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DISEASE REACTION AND AGRONOMIC CHARACTERS OF CERTAIN TRITICUM-AGROPYRON CROSSES

by

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INTRODUCTION

Triticum-*Agropyron* hybridization has advanced so rapidly since the first successful cross was obtained in 1930 that it has already attained major importance in the field of plant breeding. It had a similar origin with *Triticum*-*Aegilops*, *Triticum*-*Secale*, and similar crosses in phylogenetic investigations, but has far outdistanced them in usefulness as well as in popularity. Today, 18 years after the initial successful hybridization, scores of investigators are spending all or part of their time in this new field of plant breeding; the most extensive investigations are being carried on in Russia, Canada, and the United States, but work has also been reported from South Africa (5), Australia (51), Italy (19), and Germany (13).

Armstrong (7) credits the Russian scientist, N. V. Tzitzin (also transliterated as Zizine or Cicin), with obtaining the first successful hybrids in 1930. Though this is generally conceded, Reitz, et al. (52) state that Hillman reported obtaining a hybrid as early as 1903 but that the authenticity of the cross is doubtful. They further credit W. J. Sando with obtaining the first fertile hybrids in the United States in 1935 after having worked with them since 1923. McFadden, according to McFadden and Sears (39), became interested in their possibilities as early as 1914 and reported on his hybridization attempts. According to Armstrong (7), the first Canadian crosses were obtained in 1935. Since then, many workers have reported obtaining hybrids between the different species of the two genera.

An evaluation of the *Triticum*-*Agropyron* hybrids is still difficult; if commercial acreage is taken as an index, then they have not yet established themselves. Although the popular press, Davies (16) in the *Country Gentleman*, November, 1944, and Strohm (71) in the *Kansas Farmer*, November, 1946, hints at commercial acreage in Russia, scientific literature presents the program as still in the experimental stage; this is especially true of the wheat-like types, but it is possible that the fodder types are being increased extensively in Russia (28) and Canada (10).

Their permanent importance has led Soleznev and Tomaševič (62) to name them *Agrotriticea*; Khižnjak (29) further suggests that the term, *Agrotriticum*, plus the name of the wheat species be used to identify the new forms; e.g., *Agrotriticum durum*.

The objectives to be gained from this hybridization have been similar in the various countries. The Russians have, however, placed a premium on the perennial derivatives; the Canadians are largely interested in a large-seeded forage type, while the workers in the United States have been very anxious to transfer the many disease resistance qualities of the *Agropyron* species to wheat. The utility of a perennial wheat in Kansas is not very great; the maintenance of stand, its chief value, would require the utilization of moisture and nutrients needed for making a grain crop.

In 1928 McFadden, according to McFadden and Sears (39), listed the following desirable attributes in the Agropyron species that might be transferred to the wheats: perennial nature, resistance to heat and drought, extreme winterhardiness, resistance to alkaline and acid soil conditions, resistance to various diseases, and wide geographic adaptation. Reitz, et al. (52) have listed the three possible derivatives from such hybridization as:

> 1. a long-lived wheat-like plant that would yield a harvest of grain in consecutive years from one sowing; 2. a dual-purpose type yielding some grain and suitable forage; and 3. a forage type might be developed with seeds larger than those of the common grasses.

The article, "Exploring Unusual Possibilities in Plant Breeding", Yearbook of Agriculture, U. S. Dept. Agric., 1936, states on page 197:

> The measure of success attained from such wide crosses will depend on the amount of hybrid material produced; the training, patience, and persistence of the investigator; and his ability to recognize what is valuable in a large mass of material, most of which is worthless (3).

It is the purpose of this thesis to review the literature dealing with the results obtained from Triticum-Agropyron hybridization and to present additional experimental data, in order to determine the measure of success attained in this new field of plant breeding.

REVIEW OF LITERATURE

The literature concerning the Triticum-Agropyron hybridization is becoming so extensive that it is difficult to review all of the material published. While a majority of the papers or abstracts of the originals will be reviewed, attention should be called to a number of reviews available that give a rather comprehensive view of the investigations. The Russian work up to and including 1936 has been compiled by Tzitzin (74). The cytology of the Agropyron species and their Triticum hybrids was reviewed extensively by Aase (2) in 1946, and briefly by Sears (61) in 1948. The earlier Canadian hybridization results are presented by Johnson (22), and brought up-to-date by Armstrong and Stevenson (10) in 1947. The breeding results in the United States were reviewed by Smith (67, 68) in 1942 and 1943; Suneson and Pope (72) present the program as of 1946, especially the work at the California Station; Vinall and Hein (86), in 1937, compiled an extensive record of Agropyron chromosome numbers and the dates of the earliest reported crosses in Russia, Canada, and the United States.

The Agropyron Species

According to Hoover, et al. (20), the Agropyron genus, commonly known as the wheatgrasses (from agrios, wild, and pyros, wheat), contains approximately 150 mostly perennial species widely distributed throughout the temperate regions. The majority, 100, are native to Eurasia while 30 occur in North America; the remaining ones are found mostly in South America. Of these, only a small number have been tried in wheat X wheatgrass crosses, and only a few of these have been successfully used. Sears (61) states that the Agropyron genus represents a polyploid series with a basic number of seven chromosomes similar to that of the other members of the sub-tribe Triticeae and shows the highest degree of polyploidy of any of them. Most of the "crossable" species are in the higher polyploid groups; this has led Vakar (79) to suggest that these forms be included in the genus Triticum. It has been indicated by Smith (68) and many others that crossing within the Triticum genus often gives much poorer seed set than that obtained in certain Triticum-Agropyron crosses.

Many investigators report widely varying crossing results even when using the same Triticum and Agropyron species. This has led Armstrong (7) to suggest that polymorphic forms exist within the Agropyron species. Polymorphic forms of A. elongatum (2n = 70) have been reported by Armstrong (7) and Sapehin (55), the latter reporting one form with only 56 somatic chromosomes. Araratjan (6) found diploid, tetraploid, and hexaploid forms in A. cristatum; Smith (67) states that polymorphic forms of A. repens exist. Tzitzin is quoted by Armstrong (7) as having found numerous strains of A. glaucum; the results obtained by Sipkov (65) agree with Tzitzin's, for some of his A. glaucum strains gave hybrids which formed only two to three bivalents at meiosis while others formed 14 pair. Veruschkine and Shechurdine (85) working with *A. intermedium* (synonym for *A. glaucum*) concluded that both it and *A. elongatum* had several well-defined forms and varieties. Vakar (78) states that, in general, the *Agropyrons* exist as polymorphic forms which vary in chromosome numbers. Here, then, is the key to the widely-divergent results reported when local forms were used in the crosses.

Agropyron Species Used in the Crosses

It has already been indicated that only a small number of the Agropyron species cross successfully with wheat. The delay in securing fertile hybrids (or even sterile ones) can, then, be at least partly ascribed to the use of species that do not cross successfully with wheat. Tzitzin's success in 1930, then, is partly due to the fact that he had at hand the two native Russian wheatgrasses that cross most readily with wheat - *Agropyron elongatum*, and *A. glaucum* (*intermedium*). Native North American wheatgrasses do not cross readily with wheat, thus forcing American plant breeders to rely on foreign introductions. Nearly every species used successfully is native to Russia or Eurasia.

Almost without exception, investigators attempting the hybridization, report success when using *A. elongatum*.

Agropyron glaucum (*intermedium*) also crosses quite readily, as reported by Armstrong (8, 9, 10), Peto (45), Peto and Young (48), Vakar (81), Veruschkino (82), and many others. Lapchenko (31) reports that both *A. glaucum* and *A. elongatum* have been crossed with 200 different varieties of wheat, and adds that the success is higher when the wheat varieties themselves are of hybrid origin. *Agropyron elongatum* has been crossed successfully with nearly every wheat species; the greatest difficulty is encountered in crosses with *Triticum monococcum* and *T. timopheevi*. White (89) reports that Tzitzin obtained a cross with *T. monococcum* while Veruschkino (82) crossed *T. monococcum* with *A. intermedium*; Popova (49, 50) used *T. timopheevi* successfully in crosses with both *A. elongatum* and *A. glaucum*.

Armstrong (8) and Armstrong and Stevenson (10) indicated only slight success when using *A. junceum*, *A. pincium*, and *A. trichophorum*. A hybrid was obtained by Östergren (42) from the cross, *A. junceum* X *Triticum turgidum*. White (89) was unable to secure hybrids from crosses involving *A. junceum*, but reports that Russian workers state that it crosses readily with wheat; Johnson (22) got one hybrid in a cross with *T. persicum*, var. Black Persian.

Varying degrees of success have been reported with the use of *Agropyron trichophorum*. Love and Suneson (33) have made extensive use of *A. trichophorum* in crosses with *Triticum macha* and *T. durum*, var. Mindum. Smith (67, 68) also obtained a high percentage of seed set and hybrids in crosses with *T. durum* and

T. aestivum, var. Mosida and Turkey-Florence. In contrast, White (89) reports only a low degree of success in the use of *A. trichophorum*.

A hybrid between *Agropyron cristatum* and *Triticum timophoevi* was reported by Woruschkin (88), but Johnson (22) and Smith (67) had no success in crosses with *T. durum* and *T. vulgare*; Smith did obtain one dwarf plant with Rex (*T. aestivum*), but it died in the seedling stage. Smith (68) is the only one reporting work with *A. amurense* (an *A. intermedium* variate), which he crossed successfully with *T. durum* and *T. aestivum*.

Seeds have in a few cases been obtained from some of the other crosses attempted, but, in general, no hybrids with the exception of those reported by Kovaleva (30) for *A. obtusiuscum* - probably *obtusiusculum* - were produced in experiments involving the following species:

Johnson (22):	*Germless seeds*	*Complete failure*
	A. desertorum	*A. pauciflorum*
	A. imbricatum	*A. obtusiusculum* = *intermedium* (86)
	A. sibiricum	*A. griffithsii*
	A. dasystachyum	*A. smithii*
		A. caninum
		A. richardsonii = *subsecundum* (86)

	Seeds only	Complete failure
Smith (67):	*A. dasystachyum*	*A. caninum*
		A. ciliare
		A. inerme
		A. pungens
		A. sibiricum
		A. smithii
		A. trachycaulum
		A. semicostatum

According to Vinall and Hein (86), the majority of the above species have a somatic chromosome number of 28. *Agropyron repens*, *A. pungens*, *A. trichophorum*, and *A. intermedium* have 42, while *A. smithii* Rydb. has 56 and *A. elongatum*, 70. Thus, the higher chromosome-number species, with the exception of *A. smithii*, appear to be the more "crossable" types.

Cytology of the *Agropyron* Species

Aase (2) states that very little is known concerning the cytogenetical relationship within the large genus *Agropyron*. Peto (45), Vakar (79), and Östergren (41) are about the only ones to study the cytological behavior of the *Agropyron* species used, and they have limited their observations to a few species. Peto found that at meiosis the hexaploid *A. glaucum* formed a large proportion of bivalents with occasional univalents and multivalents (quadrivalents); this has led Aase to suggest that previous interchange of segments between non-homologous chromosomes must have occurred and that the tetraploid A. intermedium lacks at least one genome that is present in the hexaploid; but the phenotypic difference has not been great enough to raise both to a separate specific rank.

Love and Suneson (33), who have worked most extensively with A. trichophorum, state that its meiotic behavior has not been studied.

When examining the decaploid A. elongatum, Peto (45) found a very unusual situation in that uni-, bi-, tri-, quadri-, quinqui-, sexa-, and octavalent configurations occurred. Vakar (79), however, found a normal pairing of 35 bivalents. Both agree that A. elongatum is an amphidiploid from a cross between a hexaploid and a tetraploid Agropyron with subsequent doubling; they suggest that the hexaploid A. intermedium (glaucum) was involved.

Cytological examination of the tetraploid A. junceum revealed univalents in 10 per cent of the cells examined, according to Östergren (41); for the hexaploid A. repens, he found univalents in all plants studied and quadrivalents in some.

A high degree of instability is, thus, evident in most of this genus. Many naturally-occurring hybrids have been found in the cross-pollinated genus Agropyron. Veruschkine (82) states that A. intermedium and A. trichophorum cross readily in nature, but an attempted cross between A. intermedium and A. repens failed. Östergren (41) reports that spontaneous hybrids between *A. repens* and *A. junceum* have been found in a number of localities in Sweden. Sears (61) suggests that the polyploid series in *Agropyron* is essentially of an autoploid nature; e.g., *A. cristatum* (2X, 4X, 6X); *A. spicatum* (2X, 4X); *A. junceum* (4X, 6X); and *A. intermedium* (4X, 6X). The presence, however, of so many spontaneous hybrids is suggestive of both auto- and allopolyploidy.

Seed Set and Fertility

The obtaining of the F_1 seed is, of course, the initial step in hybridization; seed set is expected to be highest when the pairing behavior is the more nearly normal, but seeds set often produce hybrid plants which exhibit no tendency to pair at meiosis. Thus, there appears to be a matter of compatibility apart from pairing tendencies; but, in general, seed set may be expected to be correlated with pairing behavior.

The literature concerning seed set when using the different species is somewhat contradictory; this may be due partially to the polymorphic strains of *Agropyron* and the different wheat varieties used in the crosses. White (89) reports that, in general, the seed set is higher when using *A. elongatum* than with *A. glaucum*, and that the tetraploid wheats give twice the success of the hexaploid wheats. Using the winter wheats, Kovaleva (30) also found the seed set to be higher when using *A. elongatum* and further observed that the soft winter wheats were better utilized than the hard winter wheats. Lapchenko (31), however, states that success is usually better with A. glaucum than with A. elongatum. It may be, however, that he is referring to the long time result and not to the initial cross. Armstrong (8) compared his results obtained when using tetraploid and hexaploid wheats and found that the former gave the highest seed set, in general, with the two named Agropyron species; however, in each case his results were better when using A. glaucum; tetraploid wheat X A. glaucum, 17.4 per cent, and with A. elongatum, 14.7 per cent; hexaploid wheat with A. glaucum, 7.1 per cent, and with A. elongatum, 1.9 per cent. Schneidermann (58) found higher percentage of seed set, but otherwise agreed with Armstrong's work; his results were: Triticum vulgare X A. intermedium, 29.4 per cent, with A. elongatum, 20.5 per cent; T. durum X A. intermedium, 53.6 per cent, with A. elongatum, 35 per cent.

Smith (67), in 1942, reported that, in general, he obtained a higher seed set when using a short form of A. intermedium; results were also better with A. trichophorum than with A. elongatum, though not as much effort was made to obtain hybrids with the latter. Using A. trichophorum, A. intermedium, and A. amurense in the next year, 1943, he (68) reported that great variability can be expected due to the varietal differences in the wheats used, but that, in general, durum varieties are more compatible in the crosses; average seed set from all combinations was highest when using A. trichophorum, followed by A. intermedium and A. amurense in that order. A general average seed set of 50 per cent was reported by Artemova (11) for A. trichophorum, A. elongatum, and A. intermedium. When using the other Agropyron species, investigators, in general, report a very low percentage.

The use of the wheat plant as female parent is generally reported to give a higher crossing percentage than when the reciprocal cross was attempted.

Sterility in the F_1 hybrid has been the next obstacle in Triticum-Agropyron hybridization. Veruschkine (82) indicates that the fertility of A. intermedium and A. trichophorum hybrids is distinctly less than that of A. elongatum hybrids. Lapchenko (31) reported that the A. elongatum F_1 hybrid was three to five per cent self-fertile as compared with the completely sterile A. glaucum F_1 hybrid; in contrast the F_2 A. glaucum hybrids were 81.7 per cent fertile as compared with the 54.8 per cent for the A. elongatum F_2 hybrids. The A. elongatum hybrids were also reported as being more fertile in the F_1 by Schneidermann (58). Popova (50) obtained only one grain in two years from a Triticum timopheevi X A. elongatum hybrid and none from the cross with A. glaucum. After four generations of line breeding, Armstrong (8) reports a gradual increase in fertility; the literature is generally in agreement with this.

Cytology of the Hybrids

From evidence obtained in interspecific hybridization, Sax (56), in 1922, stated that, in general, sterility increases as the proportion of univalent chromosomes in reduction division increases. Thompson (73), in 1930, underscored the work of Sax and added that a shrivelled endosperm in cereals was indicative of this same chromosomal unbalance - the unbalance always being the more exaggerated because of its 3n condition. Armstrong (8) noticed a significant correlation between chromosome numbers and fertility in advanced generations. During the early years of Triticum-Agropyron hybridization, the Russians did extensive cytological work and correlated sterility with lack of chromosome pairing during meiosis; of late, however, different theories have been advanced. Tzitzin (77) quotes Kikot and Volkova as stating that similarity in chromosome number is not the main factor in determining fertility. Schneidermann (58) definitely states that the environment, not chromosome compatibility or incompatibility, is the chief factor in fertility or sterility. Armstrong and McLennan (9) agree that failure of chromosomes to pair may not be due to a lack of homology, but that temperature and genetic factors may disturb the cytodynamics of the cell. It was recognized by Vakar (79), however, that hybrids in which pairing was complete were entirely self-fertile; cases of high bivalent formation accompanied by high sterility are, however, reported by Popova (50) and Khižnjak (27).

Reports of no pairing to complete pairing at meiosis are found in the literature, the amount depending on the species and strains of *Agropyron* and *Triticum* used. Pairing has been used by Vakar (79, 81), Popova (49, 50), Peto (45), Love and Suneson (33), McFadden and Sears (38, 39) to establish chromosomal and genome homology between the two genera.

From his cytological examination of the hybrid material, Peto (45) suggested that either the A or B genome of wheat is present in *A. glaucum* and *A. elongatum*; then, *A. glaucum* could have the genome formula of A X_1 Y_1, and *A. elongatum*, A X_1 X_2 Y_1 Y_2. Thus, in a cross of *A. elongatum* with *Triticum vulgare* up to 21 bivalents might be expected from allosyndesis of the A genomes and autosyndesis of the X_1 X_2, and Y_1 Y_2, leaving only the B and C as 14 univalents. He actually observed two sets of unpaired chromosomes and many multivalents in *T. vulgare* X *A. elongatum* hybrids. In crosses with *A.* glaucum, he observed an average of only 4.8-6.2 bivalents, substantiating his theory that they must have one set in common. Vakar (79), in crosses of *T. vulgare* X *A. elongatum*, somatic chromosome number of 56, found that in reduction division usually 42 or 35 chromosomes were formed - in the first case 14 bivalents and 28 univalents, and in the second case 21 bivalents and 14 univalents; later (80), he observed in the same cross an average of 10 bivalents with a maximum of 28 bivalents, and, therefore, suggested that *A. elongatum* must have three sets of chromosomes in common with wheat, designating them as A_a, B_a, and D_a (following the Japanese system). The 28 bivalents could, then, be explained on the basis of allosyndesis of A_aA_t, B_aB_t, D_aD_t genomes and autosyndesis of the two *Agropyron* sets of X_1X_2. *Agropyron glaucum*, he believed to be of the designation A_a, D_a, and X_1.

Khižnjak (27) agrees with Vakar that *A. elongatum* has the A, B, and D genomes homologous with wheat and two genomes, X_1 and X_2, not found in wheat. If *A. elongatum* is, then, an amphidiploid of a tetraploid and hexaploid, and *A. intermedium* is the hexaploid involved, then *A. intermedium* must be A_a,D_a (or C_a), X_1, and the tetraploid, B_a, X_2 (not the tetraploid *A. intermedium*, however). In crosses of *T. vulgare* X *A. intermedium*, Vakar (81) found 7 to 14 bivalents in the F_1, depending on the strain of *A. intermedium* used; the F_2 invariably had up to 21 pair while the F_3 had from 21 to 28 bivalents. Therefore, he suggested as indicated above, *A. intermedium* must have the A and D genomes in common with *vulgare* wheats; in addition, he indicated that the A genomes were more homologous than the D and, therefore, more chromosome exchange could be expected in them. Sapehin (55) found 21 bivalents and 7 univalents in a cross of *T. vulgare* and *A. elongatum* that had only 56 somatic chromosomes, but with *A. glaucum* could get only 2 to 3 bivalents. *T. durum* gave an average of 10 bivalents in crosses with *A. glaucum*, according to literature reviewed by Peto (45), indicating that they possibly had two genomes in common, the A and B. The apparent discrepancy may be due to the inability to determine exactly which genome is actually being paired at reduction division.

Popova (49, 50) has underscored Vakar's theories by noting the results of T. timopheevi crosses with A. elongatum and A. glaucum. In the first cross, 21 bivalents and 7 univalents were found which suggested pairing of A_aA_t, B_aG_t, X_1X_2, leaving the 7 univalents of D. In the second cross, only 2 to 7 bivalents occurred - these having been formed by the A_aA_t genomes; why X_1X_2 could not or did not provide the bivalents is not explained.

Working with A. trichophorum, Suneson and Pope (72) noted that, in general, the pairing is very loose and incomplete. Love and Suneson (33), in an earlier report on A. trichophorum hybrids, report a great deal of variation; in T. durum var. Mindum X A. trichophorum hybrids, 2n = 35, they could find but few chromosomes in common and what pairing there was might have been due to homology of parts and not whole chromosomes. Fifty nuclei at first metaphase of two F_1 plants were examined One plant had an average of 1.60 pairs; five different pairing arrangements of the 35 chromosomes were seen. The second plant had an average of 6.06 pairs with 20 different pairing arrangements. Closed bivalents were rarely seen. In a plant, with 56 chromosomes, having arisen from an unreduced fertilized gamete, 20 pairs were observed, 11 of which were ring bivalents;

polyploids with 2n = 70 were not true amphidiploids, for 35 bivalents were not seen, 27 being the highest number, of which only 17 were closed and of these only three pairs were really homologous. In *T. macha* X *A. trichophorum* crosses, 2n = 41, only three closed pairs were observed; one derivative with 2n = 70 had 24 pairs, 10 of which were ring bivalents; six chains of three were observed and as many as 20 chromosomes were involved in multiple associations. In all, 44 different pairing arrangements were observed in the 50 cells examined. Apparently *A. trichophorum* has few chromosomes in common with either *T. durum* or *T. macha*.

Östergren (42) indicates that the zero to seven bivalents that he reported in the *T. turgidum* X *A. junceum* hybrid may be due to allosyndetic pairing of the wheat and *Agropyron* chromosomes, or autosyndesis of either set; the latter appears to be more probable.

The amount of pairing increases in advanced generations; Armstrong and Stevenson (10) report that in F_5 Vernal emmer X *A. elongatum*, 2n = 54, 25 pairs and two irregular pairs were noted, denoting that genetic stability was only one pair away. Vakar (81), working with F_1 to F_6 *A. intermedium* X *T. vulgare*, also reports more pairing in the advanced generations.

Methods of Obtaining Fertile Hybrids

The success of the hybridization program depends on the fertility of the hybrids; in order to achieve this, a number of techniques have been employed. Armstrong (8) has placed these into three categories: namely, line breeding, backcrossing, and the production of amphidiploids. The Russians also advise crossing the F_1 to advanced hybrids of similar crosses.

The hybrid material has been most often seeded in bulks for a number of years. From these bulks, the more fertile types have been selected for line breeding. The fertile types may have obtained functional chromosome complements due to loss or gain of univalents following random assortment at meiosis. The F_5 Vernal emmer X *A. elongatum*, 2n = 54, with 25 pairs of chromosomes is a good example of fertility being achieved as a result of line breeding. Sunoson and Pope (72) indicate that even in the more stable lines the percentage of F_1's exceeds five per cent; this random crossing is of much practical importance and suggests that considerable progress can be expected from the seeding of bulks and subsequent line selection. Nevertheless, after seven years of line breeding none of the perennial types had been completely stabilized. The Russians have reported stable lines in a much shorter time. According to Armstrong (8), four generations of line breeding have been effective in securing a gradual increase in fertility, seed weights, and percentage of perennial plants in selected lines.

Backcrossing to the wheat or grass parent, depending on which type is desired, has the advantage of giving the desired type more quickly. Those wanting to obtain the wheat-like derivatives should use this method, for such characters as quality can be best accumulated in this manner. It is to be expected that backcrossing to wheat would give more annual segregates, as indicated by Armstrong (8).

The production of amphidiploids, theoretically, should result in complete fertility and stabilization of the chromosome number at the amphidiploid level with grass chromosomes pairing *inter se* and wheat chromosomes also pairing *inter se*. Amphidiploids may arise naturally due to the union of two unreduced gametes or may be effected by mechanical or chemical means. Raw (51), in 1939, reported the first use of colchicine to obtain fertile amphidiploids from a sterile intergeneric cross of *T. vulgare* X *A. intermedium*. Earlier, Peto (46) had used hot and cold temperature treatments at meiosis to effect chromosome doubling. He increased the somatic chromosome number of a *T. vulgare* X *A. glaucum* hybrid from 42 to 84, but the progeny were weak and did not produce spikes. Since then, Peto and Boyes (47) and Peto and Young (48) have utilized gelatin colchicine capsules placed on the cut stems at tillering time to obtain amphidiploids of *A. glaucum* with *T. vulgare*, *T. durum*, Vernal emmer, and *T. pyramidale*.

Khižnjak (28, 29) reports amphidiploids, 2n = 70, of *T.*

durum and *T. persicum* with *A. intermedium* that are especially useful fodder crops; they can be propagated by cuttings as well as by seed. Armstrong and McLennan (9), working with an amphidiploid *T. turgidum* X *A. glaucum*, 2n = 70, indicate that complete pairing of the wheat chromosomes *inter se* and *Agropyron* chromosomes *inter se* did not occur. Pairings in F_1 and F_2 were imperfect, resulting in progeny with somatic chromosome numbers of 64 to 69. Partially homologous chromosomes from each parent paired to give multivalents, thus leaving some univalents; pairing was also weak and often did not persist to diakinesis. Later generations showed more complete pairing. No tendency to revert to lower chromosome numbers was observed. Amphidiploidy is the quickest way to effect fertility in crosses involving species with the lower chromosome numbers; as of 1945, Armstrong (8) reports that amphidiploids of *T. vulgare* X *A. elongatum* with 2n = 112 had not been obtained; he postulates that amphidiploidy with plants already of a highly polyploid nature is not effective, possibly due to cell size in relation to increased amount of chromatin material and to other disturbances in the cytodynamics of the cell.

Phylogenetic Relationship in the Sub-tribe *Triticeae*

From a cross of *Aegilops cylindrica* with *Triticum vulgare*, Sax and Sax (57) decided, in 1924, that a chromosomal relationship exists between some *Aegilops* species and *T. vulgare*;

they, therefore, postulated that the origin of *T. vulgare* might be due to a natural cross of some member of the *Aegilops* group with one of the emmer series. In 1926, Gaines and Aase (18) gave the genome formula of *Ae. cylindrica* as C and D. After a series of *Triticum-Aegilops* crosses, Longley and Sando (32) set the following genome formulas for some of the *Aegilops* species: *Ae. cylindrica*, B and D; *Ae. ovata*, A and D; *Ae. crassa*, B, D, and F. *Aegilops squarrosa*, according to McFadden and Sears (38), has only the C genome. *Aegilops speltoides*, however, appears to pair with chromosomes from both the A and B genomes of *Triticum*. The important point is that at least some of the *T. vulgare* genomes are present in some of the *Aegilops* species, and that possibly all three may be present in the series as a whole.

Aase (2) stated, in 1946, that *Secale cereale* apparently has no chromosomes in common with wheat. Numerous wheat-rye hybrids have, however, been obtained by amphidiploidy. In crosses of *Secale cereale* with the *Agropyron* species (especially *A. intermedium*) a higher number of bivalents have been reported than in wheat-rye hybrids. Crosses have been reported between *Secale cereale* and the following species of *Agropyron*: *repens*, *sibiricum*, and *trichophorum* (67); and *cristatum* (88). Rye, thus, seems to be closer to *Agropyron* than to wheat.

Veruschkine (82) obtained crosses of *A. intermedium* with a number of *Aegilops* species; the hybrids were perennial, intermediate between them, and partially self-fertile.

Vakar, thus, maintains that *Agropyron* genus is related to the *Secale* and *Aegilops* genera as well as to the *Triticum* genera. Veruschkine (83) early (1935) suggested that *Agropyron* might contain the ancestors of *Triticum*.

The basic number in this group of cereals is five and not seven as is commonly believed, according to Pathak (43). This would account for some of the peculiar bivalent numbers obtained and indicate that chromosome behavior may not be on a strictly genome basis *inter se*, but may overlap from one genome to another. He further states that chromosome morphology in the A and B sets of the emmers is sufficiently different to indicate that B is not a duplication of A and, therefore, must have come from a different source. Some of Vakar's work also indicates that the "wheat" chromosomes in *Agropyron* may not all be from the same genome but from both the A and B.

From their experimental efforts to trace the origin of *T. spelta* and its hexaploid relatives, McFadden and Sears (38, 39) have suggested that the *Aegilops* genus probably contributed the C genome, *Triticum* the A, and *Agropyron* the B genome. *Triticum monococcum*, a diploid, apparently has the A genome in its purest form; other diploid einkorns are *T. aegilopoides*, and *T. thaoudar*. *Triticum spelta* could, then, have resulted from a cross of any one of the emmers with *Ae. squarrosa* which has the C genome. The tetraploid wheat, *T.*

persicum, may have been the emmer involved. The B genome may be located in the *Agropyron* genus, for they indicate that *Agropyron triticeum*, Gaertn., 2n = 14, a common weed in the wheat fields of southeastern Europe, has all of the major characteristics (such as free-threshing) that distinguish the Lake Dweller wheat, *T. antiquorum*, from *T. monococcum*. It is also postulated that *T. antiquorum* may be the same as *T. persicum*. This could be an amphidiploid of *T. monococcum*, with the A genome of seven chromosomes, and *A. triticeum*, with the B genome of seven chromosomes. Efforts to combine the two have failed. Another cross, *T. dicoccoides* X *Ae. speltoides*, indicates some homology of the latter's chromosome with both the A and B genomes of the former, thus adding to the confusion. *Haynaldia* may also be involved in the genome origin for in crosses with *T. vulgare* one of the seven chromosomes of *Haynaldia villosa* occasionally pairs with a C genome chromosome. At least, it serves to indicate the inter-relationship existing among *Triticum*, *Agropyron*, *Aegilops*, *Secale*, and possibly *Haynaldia*.

Differences Between the *Agropyron* and *Triticum* Species

Agropyron species differ from the *Triticum* species sharply for some characters, while for others the differences are not pronounced.

Triticum species are annual or winter annuals, while the

Agropyron species are almost exclusively perennial (86). Another major difference occurs in the expanse of the root systems; the Agropyron species may or may not be stoloniferous in habit, but are sod formers because of their extensive root systems that far exceed those produced by the Triticum species. Xerophytic leaf characters are reported by Armstrong (8) for both A. elongatum and A. glaucum. The two characters combine to produce a considerable degree of drought resistance.

There are general resemblances in growth habits and spike characters, as was recognized by the early taxonomists. However, the Agropyron species have a more brittle rachis (10). While both free-threshing and nonfree-threshing types are found in Triticum, the Agropyron species, with the exception of A. triticeum (39), have adhering glumes. Though naturally cross-pollinated, the Agropyron species are apparently highly self-fertile when bagged (86); the wheats are, of course, self-pollinated.

Triticum kernel colors are carried in the testa (red color) or in the cross-layers of the pericarp (the purple colors of some of the T. dicoccum and T. durum varieties) (15). Agropyron appears to carry aleurone colors, especially brown and green.

High tolerances of a wide range of soil pH conditions have been reported for the Agropyron species by Tzitzin and many others.

Armstrong (8) reports additional differences: namely, spike density, leaf width, scabrousness, glume widths, and awnlessness. Spikes of Agropyron are lax, but long, and contain a large number of spikelets in spite of their loose arrangement. Sharman (63) states that Agropyron glumes are straight-sided, but that the spikelets are markedly V-shaped. Awnlessness is typical of the Agropyron species used in the crosses while awned and awnless types are common in wheat.

The grain of Agropyron is small in comparison with the grain of wheats, but much higher in percentage of protein, and the common elements calcium, potassium, and phosphorus; it is, however, low in percentage of carbohydrates and nitrogen-free extract.

Inheritance of Characters

Expression of Dominance. Most investigators generally are agreed that the Agropyron habit is dominant in the F_1; Armstrong (7) states that it is more marked in A. elongatum crosses than in the A. glaucum hybrids. Agropyron elongatum dominance is greater in advanced generations than that of A. intermedium and A. trichophorum, according to Artemova (11). Verushkine (82) also noted that A. elongatum hybrids are more perennial, while A. trichophorum and A. intermedium hybrids are wheat-like. This is possibly due to the excess of Agropyron chromosomes in the A. elongatum hybrids - this preponderance being retained longer in the future generations. Vakar (79) merely states that the F_1 show marked resemblances to the grass parent. Many intermediate types are possible; in the advanced generations these predominate, according to White (89) and Armstrong (7). Complete dominance of the perennial habit in the F_1 is, perhaps, the most marked characteristic of these crosses. This has been reported by Armstrong (7), Armstrong and Stevenson (10), White (89), Johnson (22), and Veruschkine (82). Armstrong (7) found a condition of intermediacy in respect to some of the quantitative characters such as leaf width, scabrousness, spike density, awnedness, and glume width. White reports partial Agropyron dominance in the F_1, of primary root number, primary leaf-vein number, stem hollowness, leaf texture, head density, number of florets per spikelet, beak type, and glume characters; Johnson places dominance into three types: 1. complete dominance in perennial nature, vegetative vigor, and extent of root system; 2. partial dominance in shattering rachis, adherence of glumes to seeds, and winterhardiness; and, 3. intermediate inheritance in texture of mature root, size of seed, rigidity of leaf, and leaf pubescence. White, however, found the naked seed character of wheat to be partially dominant. Tzitzin (77) states that Ragulin noted Agropyron dominance in the F_1 floral structures.

In advanced generations, hybrids showing the dominant characteristics of the F_1 are few in comparison with the predominating intermediate type. White (89) found that in hexaploid wheat X A. elongatum crosses, both parental types, for most characters, were recovered by the F_3; however, the intermediate types continued to predominate. The tendency of progeny to revert back to parental types, as found in interspecific wheat crosses, is not so evident in Triticum-Agropyron crosses, according to Armstrong and Stevenson (10). This suggests that the dominant factors must be due to many genes which are reassembled slowly. Voruschkine (84) also noted that these crosses differ from most intergeneric forms by the presence of a larger number of intermediate types; dominance, he adds, must be due to a highly complex and complicated scheme of inheritance. He suggested that the origin of new forms in distant crosses is more than merely a result of recombination - rather due to mutations caused by distant hybridization. Lapchenko (31) also reported a decrease in tillering, number of perennials, and root development with advancing generations; but, he adds, the large intermediate group is the most valuable.

Hybrid Vigor. Hybrid vigor in interspecific hybridization of cereals is usually lacking. In Triticum-Agropyron hybridization, however, the F_1 has been reported more vigorous than either parent by White (89), Vakar (79), Voruschkine (82), and Johnson (22). White noted that the vigor was reduced considerably in the F_2 and future generations. Veruschkine reported that hybrid vigor is especially noticeable in A. elongatum crosses and cited as an example the deeper green color of the F_1's. Johnson (22) noted hybrid vigor as the expression of such quantitative characters as height, leafiness, tillering, and the prolongation of the vegetative period.

Stability of Hybrids. The real measure of success in the Triticum-Agropyron hybridization program is the stabilization of the desired types. Suneson and Pope (72) have pointed out that after seven years of breeding none of their perennial lines was completely stabilized; outstanding plants were difficult to fix by selection. On the other hand, Cicin (14), in 1943, reported that constant, non-segregating, perennial lines had been obtained. Homozygous reactions for rust resistance and other characters have been used by Suneson and Pope to indicate that Agropyron characters are being retained by the progeny. Amphidiploids appear to be more perennial than segregates selected by line breeding; at best, however, only limited perennialism has been attained.

Drought Resistance. Extensive investigations regarding the root systems of the hybrids have not been reported. It seems reasonable, however, to assume that the report of drought resistance can indicate inheritance of the extensive root systems of Agropyron. The influence of xerophytic leaves on drought resistance has not been estimated.

Tzitzin (74), in 1936, reported hybrids that had luxuriant root systems; later, he stated that they had an uncommon degree of resistance and were tolerant to various kinds of drought. Suneson and Pope (72) state that part of the drought resistance of *A. trichophorum* hybrids under California conditions is due to the fact that their dormancy period coincides with the driest season of the year; this dormancy is inherited and cannot be broken even with irrigation treatments. In 1937, Tzitzin (77), citing Udol'skoja's work, stated that drought resistance is due to the fact that the hybrids lose less water during drought periods, partly due to leaf structure; detached leaves of the hybrids lost water more slowly than detached wheat leaves. In addition, they appear to possess an unusual vigor of assimilation immediately following the drought period; this aided in their rapid recovery. Tests indicated that the osmotic pressure rose higher in the hybrids than in wheat plants during the drought periods. Artemova and Jakovleva (12) reported that some of the perennial hybrids still yielded 9.6 centers per hectare in a dry year in the already arid regions of Kazahstan. Cicin (14), in 1943, reported constant hybrids highly resistant to drought.

Winterhardiness. Breeding for resistance to cold has been one of the major emphases of the Russians; and, consequently, they have studied it more thoroughly. Tzitzin (77), in 1937, reviewed the work done by Blinkova and Malakhov. Blinkova states that winterhardiness is related to the temperature necessary for protein coagulation (proteins of the hardier varieties requiring a higher temperature) and to maintenance of a high sugar content. The latter is correlated with a low respiration rate. *Agropyron elongatum*, one of the hardiest species, has the lowest respiration rate of the *Agropyron* species studied. Greater amounts of sugars are accumulated in the hardy hybrids during autumn hardening, and the reduction of water content is more pronounced.

A marked difference in color between young and old leaves was noted; this permits assimilation to continue throughout the day - in the weak light by dark leaves, and in strong light by paler leaves. Some hybrids were reported to reach a sugar content of 21 per cent by three o'clock in the afternoon. Plants having no water-extract protein in the fall were the hardiest of all and needed less autumn hardening; it is significant that *A. elongatum* has none. Phasic development is, thus, closely tied up with protein properties. Protein coagulation temperatures reported for *A. elongatum* were 62-71 degrees centigrade; for *Lutescens* 062 X *A. glaucum* hybrids, 72-75 degrees centigrade; and for *Lutescens* 0329, 57 degrees centigrade.

Malakhov reported that the dry matter content in stolons rose consistently, leaving a large supply of nutrients for winter and spring; a similar rise was noted for starch content, but the soluble sugars decreased until flowering time.

Requirements for a cold-resistant plant have been listed by Tzitzin (76) as: having a long thermo stage; consuming the least food during the winter; capable of maximum food production; and having the maximum amount of bound water. High protein content was also given as a possible factor (76). Suneson and Pope (72) also noted that nitrogen (a component of protein) appears to be a limiting factor in winter survival.

Kovaleva (30) reported that the hybrids were not winter hardy until well past the two to three leaf stage. Johnson (22) found that the hybrids were about equal to the Agropyron parent in winter hardiness; *A. elongatum* hybrids are the hardiest, according to Artemova (11).

A general decrease in winter survival with succeeding generations was reported by Armstrong (8). White (89) reported that the F_1 of wheat X *A. elongatum* had the highest winter survival; no difference was reported in the use of spring or winter wheats, but the tetraploid wheats gave the highest survival. Survival decreased at least 50 per cent with each advance in generation (under Canadian conditions). He cites Tzitzin's results of 73.2 per cent winter survival in the F_2, 30.7 per cent in the F_3, and one per cent in the F_4. Backcrossing to wheat resulted in a material drop in survival; Armstrong's results are cited for F_2 winter survival of 94.7 to 97.2 per cent as compared to the second-generation backcross survival of 26.6 to 29.4 per cent.

Most of the survival values reported have been from areas of extremely cold winters; thus, their winter-hardiness value for the more temperate winter wheat areas cannot be ascertained.

Veruschkine (84) has emphasized that the inheritance of resistance to cold is highly complicated.

Tolerance of Saline Soils. Tolerance of the hybrids to soil salinity has been reported by Tzitzin (74), in 1936, and again by Cicin (14), in 1943. Skosyreva (66), in 1944, reported sand culture results indicating that grain yield of the hybrids was still normal in a Hellriegel's solution containing 0.25 per cent NaCl; in a one per cent solution, the plant still formed some grain. The control plant, Caesium 0111, produced some grain in the first instance but failed to live in the one per cent solution. With Na_2SO_4, even better results were obtained. Protein content was higher than usual in plants grown in the salt solutions.

Disease and Insect Resistance. Johnston (23), in 1940, reported results of testing 15 of the more common Agropyron species with Puccinia triticina Eriks., leaf rust of wheat, physiologic races 5, 9, 15, 28, and 37. Of the 15 species tested, 12 had immune or near-immune reactions; all of the commonly used Agropyron species in Triticum-Agropyron hybridization were in the highly resistant group. Hybrids of T. vulgare X A. elongatum also showed near-immunity. White (89) states that the rust resistance of A. glaucum is lower than that of A. elongatum. Under the rust conditions of 1938 in Canada, he noted no leaf or stem rust on F_1, F_2, or F_3 hybrid material. The F_4 of Marquis X A. elongatum was still rust resistant, indicating that the resistance factors must have come from Agropyron. Resistance appeared to be highly dominant and due to several factors, for the proportion of susceptible segregates was small even in large populations. Resistance of *A. elongatum* to rusts was also noted by Tzitzin, Veruschkine, and Armstrong.

Wheat X *A. elongatum* hybrids tested by Reitz, et al., (52) were all resistant to the races of stem rust used; many had zero readings for leaf rust. Mindum X *A. trichophorum* hybrids showed the highest degree of resistance to both leaf and stem rust. Three amphidiploids of *A. glaucum* with Vernal emmer, *T. turgidum*, and Kharkof, also gave a consistently high degree of leaf and stem rust resistance. Patterson (44), using nine races of leaf rust of wheat and two races of stem rust of wheat, *Puccinia graminis tritici* Eriks. and Henn., found many lines of wheat X *A. elongatum* immune or highly resistant to all races used. Humphrey, et al. (21), however, reported *A. repens* resistant but many of its relatives susceptible to stem rust of wheat.

Love and Suneson (33), and Suneson and Pope (72) did not find the Mindum X *A. trichophorum* segregates as resistant to stem and leaf rust as had been reported for the other crosses; some immune segregates were obtained, however. Veruschkine (82), on the other hand, reports the most rust resistance for *T. durum* crossed with *A. intermedium* and *A. trichophorum*.

Resistance to yellow rust (presumably stripe rust of wheat, *Puccinia glumarum* (Schm.) Eriks. and Henn.,) by *Agropyron* hybrids was reported by Schneidermann (59).

The use of these hybrids as a new source of rust resistance in wheat breeding programs is evident.

Speckled leaf blotch of wheat, *Septoria tritici* Rob., is a more detrimental wheat disease than most observers suspect (70). Wheat, rye, and Kentucky bluegrass are the only known hosts, according to Weber (87), 1922. Sprague (69), in 1934, reported a physiologic form of *Septoria tritici* on oats, but later, 1944, indicated it was probably not. Luthra, et al. (34), reported *Triticum durum* immune to the disease. Sprague could get no infection on rye. He also cited a report by C. O. Johnston, who in 1939 noted that Kawvale and most of the soft red winter wheats were heavily infected; the hard red winter wheats showed fewer lesions.

Weber reported infection of 10 to 100 per cent of the wheat seedlings near Madison, Wisconsin, in 1920. Large numbers of seedlings were killed; usually the infection is not that severe. The disease affects the leaves only, killing them and thereby reducing the photosynthetic power of the plant. The disease is worst during open and wet winters. *Septoria tritici* Rob., speckled leaf blotch of wheat, did not infect *A. cristatum*, according to Sprague (70), nor *A. repens*, according to Weber (87). Luthra, et al. (34), indicated its rising importance as a wheat disease in India. Speckled leaf blotch has been a contributing factor to the reduction of wheat acreage in Arkansas, according to Rosen (53).

Fellows (17) has not found physiologic races within

Septoria tritici; he reports, however, that isolates of the disease from different areas differ in the virulence with which they attack susceptible plants. There is no evidence of specialization for any variety, however.

Tzitzin (76), in 1937, reported a number of hybrids immune to bunt, *Tilletia* spp., under conditions which gave high infection in such standard varieties as *Caesium* 0111 and *Milturum* 0321. Many hybrids were also immune to loose smut, *Ustilago* species. Smut resistance has also been reported by Artemova (11), Armstrong in a number of publications, Veruschkine (82), Smith (67), and by Schneidermann (59). Novitskii (40), in 1941, stated that the hybrids are more resistant to *Tilletia* spp. than to *Ustilago* species. Patterson (44) reported the presence of bunt in wheat X *A. elongatum* hybrids from natural infection under field conditions.

Resistance to mildew, presumably powdery mildew *Erysiphe graminis tritici* El. Marchal., has been noted by Reitz, et al. (52). Smith (67) reports that resistance has been obtained; mildew resistance is also mentioned by many others.

The presence of ergot, *Claviceps* spp., in the hybrids has been reported by White (89), Johnson (22), Armstrong (8), and Patterson (44). According to Johnson, *A. glaucum* is susceptible to ergot. He states that *A. elongatum* transmits its ergot resistance to future generations. White does not agree with the latter. All of them indicate, however, that the infection with ergot is due to sterility and that highly fertile lines will be relatively free from the disease.

Novitskii (40) also reports the *Agropyron* hybrids more resistant to *Helminthosporium* spp. and *Fusarium* spp. than *Milturum* 0321, a standard wheat variety.

A pseudo-rosette disease of cereals, "Zakuklivanie" (a virus mosaic, especially of oats), attacks most wheats in the U. S. S. R., but *A. elongatum* and *A. glaucum* are immune to it and their wheat hybrids highly resistant, according to Vovk (4).

The *Agropyrons* do not appear to be outstanding in their resistance to insect attack. Seamans and Tarstad (60) state that *A. smithii* is very susceptible to the wheat stem sawfly, *Cephus cinctus* Nort., and spreads it to wheat fields. Jones (26) found the *Agropyron* species generally susceptible to the Hessian fly, *Phytophaga destructor* Say., in terms of the number of puparia per plant, but a degree of tolerance exists. Patterson (44) found slight evidence of resistance in the *Agropyron* hybrids under a condition of light infestation.

Variation for aphid resistance by the hybrids under greenhouse conditions was noted by Reitz, et al. (52).

Agronomic Characters: Yield, Flour Qualities, Kernel Characters, Heading Date, Standing Ability. The popularly-reported extremely-high yields of the *Triticum-Agropyron* hybrids in Russia appear to have been somewhat exaggerated. Strohm (71), in 1946, reported in the *Kansas Farmer* that partly perennial hybrids had yielded up to 81 bushels per acre on the collective farms. In 1944, Artemova and Jakovleva (12) reported that perennial wheat-Agropyron hybrids in arid Kazahstan yielded 32.2 centners per hectare in 1941 and 9.6 centners in 1942, a very dry year. The measure of the centner is not given; the hectare is equal to approximately 2.47 acres. The commonly used European centner is a "hundredweight" averaging 110.23 pounds. A metric centner is equal to an average of 220.46 pounds. Therefore the 32.2 centner yield would at least be 23.95 bushels per acre, and at the most 47.9 bushels per acre. The yield in the dry year would be 7.14 bushels per acre if the first measure is used, or double that, 14.28 bushels, if the metric centner was employed. Cicin (14), in 1943, reported that constant, non-segregating Triticum-Agropyron hybrids produced four grain crops totaling 55.2 centners per hectare in two years. Converted to bushels per acre, this would be 41.1 bushels or 82.2 bushels, depending on which measure is meant. This is, of course, for two crop years. Hybrids sown in the fall of 1939 produced a grain crop, in 1940, of 18.2 centners per hectare and a hay crop of 13 centners; this yield could not have been more than that 27 bushels per acre, using the larger measure. The hay yield would not have been much more than one-half ton per acre. Such yields are well within the range of experimental yields of regular wheat varieties in this country. Reports that in the U. S. S. R. the hybrids do outyield the regular wheat varieties by as much as 50 per cent have been cited by some reviewing authors.

Suneson and Pope (72) report that the hybrids they studied never yielded more than 60 per cent of the bread wheat checks in any one harvest year.

Seleznev and Tomaševič (62) have called attention to the double utility of the hybrids in producing one crop of grain and two crops of hay in one year. Artemova (11) has indicated the potential yield by reporting one F_1 *T. vulgare* X *A. elongatum* plant that bore 150 heads which produced a total of 665 grains.

An outstanding characteristic of the *Agropyron* hybrids is the high protein content of the grain. This has been noted especially by the Russian workers. Armstrong and Stevenson (10) report the following percentages for protein in the grain: C. A. N. 1835 X *A. elongatum* hybrid, 25.0: *Lutescens* X *A. elongatum* hybrid, 27.1; Marquis, 18.4; average spring wheat, 16.0; and 12.5 for the average winter wheat. They also report the grain of the hybrids higher in minerals, calcium, potassium, and phosphorus, but lower in carbohydrates and nitrogen-free extract. The grain was not equal to wheat for milling purposes but had a high nutritive value as a feed grain.

Suneson and Pope (72) reported that the flour protein percentage was higher in the hybrid material than in bread wheats; a higher part per million carotenoid content was also found.

Tzitzin (75) states that the Agropyron protein characteristics are transmitted to the hybrids. In fact, the hybrids often exceed the Agropyron parents in this respect. A protein content of 21 per cent has been reported by Veruschkine (84) in some of the hybrids.

The most extensive milling and flour tests have been conducted by Shibaev (64). He states that, while the Agropyron species vary a good deal, the average Agropyron grain exceeds wheat in protein content by 5 to 9.5 per cent. Therefore, Triticum-Agropyron hybridization can be used to increase protein content of wheat. Gluten, he states, is the principal factor indicating bread quality and adds that a good bread of large loaf volume and good texture can only be obtained when sufficient gluten is present. The Agropyron species also vary much for gluten content; some of the lower chromosome forms, such as A. cristatum, seem to have none. He also notes that Aegilops squarossa has a gluten value of 84.0, and Ae. variabilis, 90.07. Agropyron elongatum, he found to have a wet gluten value of 68.8 and a dry value of 25.0; A. intermedium had a wet value of 52.5 and a dry value of 18.0. A Triticum-Agropyron hybrid, intermediate type, gave wet and dry gluten values of 59.2 and 20.8 respectively. This compares with the wet and dry gluten values of 50.0 and 17.5 for the standard wheat variety, Lutescens 062.

Veruschkine (84) states that the bread of the hybrids is of better quality than that of the standard Russian wheats. Tzitzin (76) reports that several produced loaf volumes exceeding Caesium 0111 by 17.5 per cent and Lutescens 062 by 24 per cent. Porosity was excellent and surpassed standard wheats. Suneson and Pope (72) also found a T. vulgare X A. elongatum hybrid that had a loaf volume of 640 cubic centimeters as compared to a loaf volume for Baart of 515 cubic centimeters. Shibaov baked bread of A. intermedium grain and found it inferior to wheat bread but distinctly better than rye bread in loaf volume, porosity, and color. Samsonov (54) who also reported that some of the Agropyron species had one and one-half times as much gluten as wheats (Caesium 0111), found the flour of Agropyron hybrids to have excellent gluten quality resulting in a normal quality loaf. He, therefore, suggests that biochemical tests of the hybrid grain be made before selecting on the basis of other characters.

Armstrong (7) noted a peculiar relationship between the different crosses and kernel weight. Tetraploid wheats X A. glaucum gave hernel weights one-half that of the kernel weight of the wheat parent; the same wheats in crosses with A. elongatum gave kernels weighing only one-third of the kernel weight of the wheat parent. In crosses of hexaploid wheat with the two Agropyron species, the opposite held true. Ho (8) also found that in the earlier generations there was a significant correlation ($r = 0.718$ with 8 degrees of freedom) between kernel plumpness and germinability. Suneson and Pope

(72) state that the 1000 kernel weight and test weight of the hybrids are considerably less than that of the bread wheats. Germination variability has also been reported by Smith (68) and others.

A variety of kernel colors have been reported for the hybrids. In *T. persicum* X *A. trichophorum* crosses, Suneson and Pope (72) obtained red, white, and blue kernels. *Triticum durum* X *A. trichophorum* produced kernels with red, light red, and blue colors; *T. vulgare* X *A. trichophorum* gave gray, red, blue, and white kernels. Red, blue, and gray kernels were obtained by Love and Suneson (33) from Mindum X *A. trichophorum* hybrids.

Only a few definite references regarding heading time were noted. The hybrids reported by Tzitzin (74), in 1936, ripened long before ordinary wheat and were reported well adapted to a short growing season. On the other hand, Schneidermann (59) states that the perennial hybrids he was working with were later than wheat. In wheat X *A. elongatum* hybrids, Patterson (44) found types earlier than Pawnee wheat, but most types were later. Since the *Agropyron* species generally head later than wheat, earliness would be an exceptional quality in the hybrids.

Lapchenko (31) is one of the few actually reporting hybrids resistant to lodging. Smith (67) reports that susceptibility to shattering and lodging has been reduced.

MATERIALS AND METHODS

Materials

The *Triticum*-*Agropyron* material studied consisted largely of *Agropyron elongatum* X wheat hybrids from W. J. Sando's crosses. Some of the material was obtained directly from him; other stocks had been grown at some of the state experimental stations. The largest group is progeny of the most wheat-like and stem rust resistant wheat X *A. elongatum* hybrids selected by D. C. Smith. A group of unidentified material, reported to be from Sando's hybrids, was received from R. H. Bamberg and Ralph M. Williams of the Moccasin, Montana, station. A number of D. C. Smith's crosses, *Agropyron* parent not identified, were obtained from A. G. Law, Pullman, Washington. The *A. trichophorum* X wheat hybrids, also from Sando's crosses, were procured from C. A. Suneson of the Davis, California, station. The wheat X *A. glaucum* hybrids, particularly the amphidiploids, came from T. M. Stevenson, Division of Forage Plants, Central Experiment Farm, Ottawa, Ontario, Canada. In addition, seeds of three of the most promising Canadian hybrids, (Chinese X *A. elongatum*) X Chinese F_7, were received in 1947. One Russian hybrid, *Triticum dicoccum farrum* X *A. glaucum*, P. I. No. 121795, K.S.C. serial number 45 TXA 70, obtained by E. R. Sears from the Siberian Agricultural Institute, Omsk, U. S. S. R., was tested.

The two unidentified groups probably have *A. elongatum*, *A. trichophorum*, and *A. intermedium* as the *Agropyron* parents. None of the lesser used Agropyron species is believed to be present in the material tested. The wheat parent is also not specifically identified in most instances. As a very high rate of natural crossing in the field seems to occur in the hybrid material, exact parentage is often not known.

Most of the *A. elongatum* X wheat hybrid material has been handled as bulks. Most of the Mindum X *A. trichophorum* material has been backcrossed to wheat and plant-selected by C. O. Johnston of the Kansas station. The 1947-48 nursery also contained a large number of rust-resistant plant selections made by Fred Patterson from the *Triticum* X *A. elongatum* hybrids, 1946 row numbers 4664-4803. When sufficient seed was available, the bulks were planted in eight-foot rows, three-foot rows were used for the smaller bulks and plant selections. All of the material, with the exception of the backcrosses, are well-advanced generations.

Rust Experiments

A group of 101 strains not previously checked for seedling reaction to leaf rust of wheat, *Puccinia rubigo-vera tritici* (Eriks.) Carleton, were tested with physiologic races 9, 15, and 126, three of the most prevalent races in the winter wheat area, and race 11, prevalent in the wheat fields of the

Pacific Coast. Inoculation was accomplished by shaking urediospores from susceptible varieties onto the 10 to 14-day old seedlings. Cheyenne, C.I. 8885, a susceptible wheat variety, was used to increase the inoculum. The inoculum, obtained from C. O. Johnston, had been checked for purity by the use of differential varieties. The seedlings were moistened with a water spray before inoculation, and then left in a canvas moist chamber for 24 hours after inoculation. Five wheat checks with known reactions were included in each test. Readings were made about 10 days after inoculation.

The three Canadian lines of (Chinese X *A. elongatum*) X Chinese F_7 were inoculated by the hypodermic needle method with physiologic races 9, 11, 15, 44, and 126 of leaf rust; physiologic races, 17 and 56, two of the most prevalent races of stem rust of wheat, *Puccinia graminis tritici* Eriks. and Henn., were also used.

The classification described by Mains and Jackson (35) was used to determine the resistance or susceptibility of the hybrids.

The 1947 leaf rust readings in the nursery are based on natural infection. Stem rust readings were not obtained. In 1948, due to unusual weather conditions, leaf rust readings were not obtained even though the susceptible spreader row was inoculated with a composite of leaf rust races. Moderate stem rust infection was obtained from natural inoculum. In addition, the spreader row was dusted with talc powder carrying the urediospores. This was applied late one evening to take advantage of the higher humidity and moisture condensation.

Septoria Experiment

Thirty-seven of the more leaf rust resistant strains were tested in the greenhouse for resistance to speckled leaf blotch of wheat, *Septoria tritici* Rob. Isolate number 26, one of the most virulent forms reported by Fellows (17) was used in the tests. The inoculum was increased on potato-dextrose agar. Conidiospores from the artificial culture were suspended in tap water; this was sprayed onto the dampened plants at four different times during the first 24 hours of the 72 hours that the plants were in the canvas moist chamber.

In order to assure more reliable results, three plantings of four plants to a pot were used. Location of the pots in the moist chamber during spraying was at random.

In order to check the effectiveness of the spray method, the first series was also inoculated by the hypodermic needle method.

Readings for resistance or susceptibility were based on the percentage of leaves infected, the number of lesions per leaf, the size of the lesions, and the location of the lesions on the leaf (on susceptible varieties the lesions appear lower on the blade). Westar, C. I. 12110, was used as the susceptible check, Nabob, C. I. 8869, the resistant check. The readings of the hybrids were then determined by comparison with the checks.

After the completion of the *Septoria* experiment, the three replications were used to study the tolerance of these strains to salt solutions. Replication I was used as the untreated check. To each pot of the third replication was added one gram of certified pure sodium chloride (NaCl) on 12/12/48. One gram of certified pure anhydrous sodium sulfate (Na_2SO_4) was added to each pot of the second replication on the same date. Later, on 12/16/48, an additional five grams of NaCl was added to each pot of the third set and an additional five grams of Na_2SO_4 to each pot of the second set. Readings for salt tolerance, based on plant appearance, were made on 12/28/48.

Determination of Agronomic Characters

Winter survival percentages in 1947 were based on an estimate of the number of dead plants per row noticed on April 11, 1947. The 1948 winter survival values on the eight-foot rows were based on the count of the dead plants and on a comparison of the hybrid rows with the check rows made on April 17, 1948. Survival percentages of the three-foot rows were computed from actual plant counts in November, 1947, and again in April, 1948.

The threshing percentages given are based on the amount of grain obtained from the first nursery threshing in comparison with the total amount recorded; the total amount is composed of the first threshing amount plus the quantity obtained when the tailings were run through a small head thresher a second time. Percentage clean threshing is a visual estimate only.

Test weights for the grain of the eight-foot rows were estimated by a method similar to the one first described by Aamodt and Torrie (1); a 27 c.c. measure with a conversion factor of 3 was used. Yields per acre for the eight-foot rows were computed by multiplying the gram weights with a conversion factor, 0.2.

EXPERIMENTAL RESULTS

Disease Reactions

Leaf Rust Tests in the Greenhouse. The results of the 101 wheat X Agropyron lines tested for seedling reaction are given in Table 1. The 1947 field leaf rust readings and the 1948 field readings for stem rust were added to indicate the performance of the hybrids under field conditions.

Eleven lines had near-immunity (0-1 infection type) readings for all four of the physiologic races of leaf rust used. Of these 11 lines, 8 appear to be Agropyron elongatum X wheat hybrids. An additional 11 lines were resistant to the same four races; some of these were nearly immune to two or three races and resistant to the others. Of this group of 11 resistant lines, 8 again were A. elongatum X wheat hybrids. Twenty-one segregating lines had predominantly near-immunity readings for all of the four races. In the susceptible group, 10 lines were completely susceptible to the four races used, while 9 were predominantly susceptible. The Russian hybrid, Triticum dicoccum farrum X A. glaucum, was susceptible. The remaining lines showed various reactions to the four races used.

The X-type readings are of some interest. Johnston and Mains (25) report that the X-type reading is common when highly resistant varieties and susceptible wheat varieties are crossed. The X-type reading indicates that resistant and susceptible reactions are present within the same leaf or plant. This indeterminate type of resistance may lead to mature plant resistance, according to Johnston and Melchers (24). This may explain why some of the lines gave susceptible readings in the seedling stage yet appeared to be resistant as mature plants in the field.

Two of the highly resistant lines (in the seedling stage) gave susceptible readings in the field; this might have been due to the presence in the nursery of a different race to which these lines were particularly susceptible. Both of the lines were also 1946 wheat-like selections from bulks that in 1947 gave susceptible readings. These selections, then, represented rust-resistant plants, since lines resistant in the seedling stage remain resistant to the same races in the mature

Table 1. Rust reactions of wheat X *Agropyron* hybrids.*

Pot no.	KSC Serial No.	Seedling reaction, leaf rust Physiologic races				Field rdg. leaf rust 1947**	Field rdg. stem rust 1948
		9	11	15	126		
	Wheat X *A. elongatum* hybrids by W. J. Sando 1946 wheat-like selections						
2	4711-1	S	S	S	S	S	MR
3	4711-1	S	S	S	S	S	MR
4	4711-4	S	S	S	S	S	MR
5	4711-4	Smr	Smr	Smr	Smr	S	MR
6	4712-1	S	S	S	S	S	S
7	4712-1	Smr	Smr	SX	Smr	S	S
8	4712-2	S	S	SX	S	S	S
9	4712-2	S	S	S	S	S	S
10	4712-3	Sx	S	Sx	S	S	S
11	4712-3	S	S	S	S	S	S
12	4725-1	X	S	X	R		S
13	4725-1	Rxs	X	XR	Xs		Seg
14	4731-1	Rx	X	Rmr	MR	S	S
15	4731-1	MR	X	R	R	S	S
16	4731-3	X	X	R	MR	S	S
17	4759-1	R	R	R	R	S	S
18	4759-2	R	R	R	R	R	S
19	4759-2	R	R	R	R	R	S
20	4777-1	R	R	MR	MR	S	Seg
21	4777-2	Rx	X	MR	MR	S	S
22	4778-2	R	Rs	Rs	Rs	Sr	R
23	4778-2	R	Rs	Rs	Rs	Sr	R
24	4778-4	R	S	Rx	S	Sr	R
25	4778-4	Rmr	Xs	R	Rs	Sr	R
26	4780-3	MR	MR	X	MR	Rs	R
27	4780-3	R	S	S	MR	Rs	R
28	4780-4	Rs	S	S	S	Rs	R
88	45 TXA 10-486	R	Xs	Xs	R	R	
89	45 TXA 13-453	R	Rmr	R	X	R	Seg
90	45 TXA 13-466	Xmr	MR	Rs	MR	R	Seg
38	45 TXA 16	R	X	Rs	MR	R	Seg
39	45 TXA 16-489	R	MR	R	R	R	Seg

Table 1. (cont.).

Pot no.	KSC Serial No.	Seedling reaction, leaf rust: Physiologic races 9	11	15	126	Field rdg. leaf rust 1947**	Field rdg. stem rust 1946
From W. J. Sando's crosses, probably wheat X *A. elongatum*							
40	45 TXA 16-490	R	MR	R	R	R	Seg
41	45 TXA 16-491	R	Rs	R	R	R	MR
42	45 TXA 16-492	R	R	R	R	R	MR
43	45 TXA 16-493	R	R	R	R	R	R
44	45 TXA 18	R	MRx	X	R	R	R
91	45 TXA 19	R	R	R	MR	R	R
92	45 TXA 21	X	S	S	S	R	S
93	45 TXA 22	X	S	S	S	R	S
94	45 TXA 23	X	X	MR	MR	R	R
95	45 TXA 24	R	Xmr	X	S	R	S
96	45 TXA 26	X	X	X	Xmr	R	S
97	45 TXA 28	Rs	Xs	X	S	R	S
98	45 TXA 29	X	X	X	S	R	S
45	45 TXA 30	MR	R	MR	R	R	R
99	45 TXA 32	X	X	X	MR	R	S
100	45 TXA 33	X	X	X	S	R	S
101	45 TXA 36	S	S	S	S	Seg	R
46	45 TXA 47			R		R	
47	45 TXA 49	R	MR	R	R	R	
31	45 TXA 50	R	MR	MR	R	R	MR
34	45 TXA 52	R	R	R	Rmr	R	R
35	45 TXA 52	MR	Rs	R	R	R	
36	45 TXA 52	R	R	R	R	R	R
37	45 TXA 52	R	R	R	R	R	Rs
Wheat X *A. trichophorum* hybrids from W. J. Sando's crosses							
29	45 TXA 51	Smr	Smr	Smr	S	Seg	Seg
30	45 TXA 53	Xmr	Smr	Smr	S	Sr	Seg
Canadian hybrids from T. M. Stevenson							
32	45 TXA 76 (Kharkov X *A. elongatum*)	R	R	R	R	R	Rs

Table 1. (cont.).

Pot no.	KSC Serial No.	Seedling reaction, leaf rust Physiologic races				Field rdg. leaf rust 1947**	Field rdg. stem rust 1946
		9	11	15	126		
		Wheat X *A. glaucum*, Canadian					
55	45 TXA 72	Rs	R	R	R	R	R
56	45 TXA 73	Rx	Xs	Rmr	Rs	R	R
57	45 TXA 75	X	Xmr	Rx	X	R	Seg
33	45 TXA 77	Rs	R	R	R	R	R
		Russian hybrid, *T. dicoccum farrum* X *A. glaucum*					
1	45 TXA 79	X	S	S	S		
		W. J. Sando hybrids, *Agropyron* parent not specified					
58	45 TXA 83	Sr	Sr	Sr.	S	Seg	Rs
59	45 TXA 84	Xs	MR	MRs	S	R	MR
60	45 TXA 85	Rx	Rx	Rs	Smr	R	MR
61	45 TXA 86	Rx	Rs	Rs	MR	R	Rs
62	45 TXA 87	R	Rmr	Rs	MR	R	MR
63	45 TXA 88	Rs	MRs	Rs	Rs	R	Sr
64	45 TXA 89	R	Rmr	MR	MRs	R	Rs
65	45 TYA 91	R	Rs	Rmr	R	R	Sr
66	45 TXA 92	S	S	S	S	R	MR
67	45 TXA 95	MR	MR	R	R	R	R
68	45 TXA 96	Rs	Rs	Rs	MR	R	Rs
69	45 TXA 97	Rs	Rs	Rs	Rs	R	Rs
70	45 TXA 98	Rxs	Rs	Rs	Rs	Seg	Sr
71	45 TXA 99	R	Rmr	Rs	R	R	Rs
72	45 TXA 100	Rmr	Rmr	Rs	Rs	R	Seg
73	45 TXA 101	R	Rmr	Rmr	RMR	R	Rs
74	45 TXA 102	Rs	RS	Sr	S	R	Seg
75	45 TXA 103	R	R	Rmr	Rmr	R	R
76	45 TXA 104	Rx	Xs	MR	Smr	R	R
77	45 TXA 105	Rs	R	Rs	R	R	Seg
78	45 TXA 106	R	Rx	R	Rmr	R	R
79	45 TXA 107	Rs	Rs	Rs	Smr	R	Rs
80	45 TXA 108	Rxs	Rs	Rs	MR	R	MR
81	45 TXA 109	Rx	Rr	R	R	R	Rs
82	45 TXA 110	R	R	Rs	R	R	Seg
83	45 TXA 111	Rxs	Rx	Rs	Rs	R	Rs
84	45 TXA 112	Rs	Xsr	Srx	Sr	R	Seg
85	45 TXA 113	R	Rs	Rs	R	R	Sr
86	45 TXA 114	R	R	R	Rs	R	Rs
87	45 TXA 118	R	R	R	R	R	Rs

Table 1. (concl.).

Pot no.	KSC Serial No.	Seedling reaction, leaf rust Physiologic races				Field rdg. leaf rust 1947**	Field rdg. stem rust 1946
		9	11	15	126		
	D. C. Smith hybrids, *Agropyron* parent not specified						
48	45 TXA 119	Smr	Smr	MRs	Rs	R	R
49	45 TXA 121	R	Rx	Rs	Rs	R	S
50	45 TXA 124		R			R	
51	45 TXA 125	R	R	Rs	Rmr	R	
52	45 TXA 126	R	R	R	R	R	
53	45 TXA 127	R	R	R	R	R	
54	45 TXA 128	Rx	S	MRs	X	R	R
102	Malakof C.I. 4898	S	R	R	S		
103	Webster C.I. 3780	S	R	R	R		
104	Loros C.I. 3779	S	S	R	S		
105	Democrat C.I. 3384	R	MR	S	S		
106	Timstein	Seg	Seg	R	R		

* X = Indeterminate type.
S = Susceptible 3 to 4 infection type.
MR = Moderate resistance 1+ to 2+ infection type.
R = Near immunity 0 to 1 infection type.
In Segregating lines, capitals indicate predominant group.

** 1947 field readings for leaf rust for pots 2 to 28 are on the bulbs from which the 1946 wheat-like selections were made.

plant stage (24).

A number of the lines highly resistant to leaf rust were susceptible to stem rust in the field. This indicates the difficulty of combining the factors for resistance in one line. Nevertheless, the high degree of resistance evidenced in the tests indicates the opportunity of selecting plants resistant to many races of both leaf and stem rust.

Three Canadian hybrids, (Chinese X A. elongatum) X Chinese F_7, received in 1947 were only moderately resistant to leaf rust, physiologic races 9, 11, and 126, and susceptible to races 15 and 44. They were, however, highly resistant to stem rust, physiologic races 17 and 56.

Reaction of the Hybrids to Leaf Rust in the Field. A summary of the leaf rust readings obtained under field conditions in 1947 is presented in Table 2. The many susceptible readings for the wheat checks (Part C) indicates that ample inoculum was present to give differential results in the hybrid material. Because they are very late season readings, the accuracy of the readings is somewhat questionable. The material is largely wheat X A. elongatum progeny.

Table 2. Class frequency of leaf rust reactions of wheat X *Agropyron* hybrids, 1947 nursery.

Part A. The eight-foot rows

Hybrid material	Number of lines in each class				
	Res.	Mod. res.	Susc.	Segregating	Total
Wheat X *A. elongatum* more or less perennial	55	1	10	9	75
Wheat X *A. elongatum* annual	33	0	16	7	56
Wheat X *A. trichophorum* more or less perennial	0	0	0	2	2
Wheat X *A. glaucum* more or less perennial	1	0	0	0	1
Wheat X *A. glaucum* annual	4	0	0	0	4
Wheat X *Agropyron* annual; *Agropyron* parent not specified	24	0	5	2	31
Total	117	1	31	20	169

Part B. Three-foot rows

Hybrid material	Res.	Mod. res.	Susc.	Segregating	Total
Wheat X *A. elongatum* more or less perennial	25	0	5	3	33
Wheat X *A. elongatum* annual	30	0	14	3	47
Mindum X *A. trichophorum* 1st backcross; more or less perennial	12	0	11	0	23
Mindum X *A. trichophorum* 1st backcross; annual	12	0	2	1	15
Wheat X *Agropyron* *Agropyron* parent not specified; more or less perennial	10	0	0	1	10
Total	89	0	32	7	128

Table 2. (concl.).

Part C. Wheat check rows

Varieties	Number of lines in each class				
	Res.	Mod. res.	Susc.	Segregating	Total
Kawvale-Marquillo X Kawvale-Tenmarq, C.I. 12128	1	3	1	1	6
Kanred, C.I.5146	0	1	4	0	5
Med-Hope X Pawnee, C.I.12141	1	1	4	0	6
Pawnee, C.I.11669	0	2	4	0	6
Cheyenne, C.I.8885	0	1	5	0	6
Total	2	8	18	1	29

Part D. Grass check rows

Species					
Agropyron smithii	1	0	0	0	1
Agropyron elongatum	3	0	0	0	3
Agropyron intermedium	2	0	0	0	2
Agropyron trichophorum	1	0	0	1	2
Agropyron glaucum	1	0	0	0	1
Secale montanum	1	0	0	0	1
Total	9	0	0	1	10

The usual high rate of leaf rust resistance is, again, evident in the hybrid material. The hybrid material was divided into annual and more-or-less perennial types. The percentage of resistant lines is much the same in both groups. It is interesting to note that the large groups are either in the resistant or susceptible classes; segregation is not too evident under field conditions. The lines giving an X reaction in the seedling stage probably are in the resistant group due to mature plant resistance.

In Part B of Table 2, another group, Mindum X *A. trichophorum*, backcrossed to wheat, does not show as high a rate of resistance as the *A. elongatum* X wheat hybrids. Because of the small numbers involved and selection that has taken place, not too much weight can be placed on these figures.

Secale montanum and all of the *Agropyron* checks, except one *A. trichophorum* strain from North Platte, Nebraska, were highly resistant.

Reaction of the Hybrids to Stem Rust in the Field. Sufficient leaf rust was not present in the field in 1948 to give differential reactions. Ample stem rust was present as evidenced by the moderate infection on Pawnee, C. I. 11669, Mod-Hope X Pawnee, C. I. 12141, and Kawvale-Marquillo X Kawvale-Tenmarq, C. I. 12128. The results of the stem rust reactions of the eight-foot rows is given in Table 3.

Table 3. Class frequency of stem rust reactions of wheat X *Agropyron* hybrids, 1949 nursery.

Part A. The eight-foot rows

Hybrid material	Number of lines in each class				
	Res.	Mod. res.	Susc.	Segregating	Total
Wheat X *A. elongatum*	60	11	1	13	85
Wheat X *A. trichophorum*	3	1	0	3	7
Wheat X *A. glaucum*	2	0	0	1	3
Wheat X *Agropyron*; parent not specified	6	2	0	23	31
Total	71	14	1	40	126

Part B. Wheat check rows

Varieties					
Med-Hope X Pawnee, C.I.12141	5	0	0	0	5
Kawvale-Marquillo X Kawvale-Tenmarq, C.I.12128	2	3	0	0	5
Pawnee, C.I.11669	4	1	0	0	5
Total	11	4	0	0	15

The wheat X *Agropyron elongatum* group is from the progeny of the wheat-like and stem rust resistant plants selected by D. C. Smith in 1942. Selection for stem rust resistance has been effective, for 60 out of 85 lines were highly resistant; an additional 11 lines were moderately resistant.

The stem rust reaction of 590 hybrid lines is given in Table 4. In this group are 281 lines selected by Fred Patterson from the large wheat X *A. elongatum* group mentioned above for both leaf and stem rust resistance on the basis of seedling reaction.

Table 4. Class frequency of stem rust reaction of wheat X *Agropyron* hybrids, 1948 nursery.

Part A. Hybrid material in three-foot rows

Hybrid material	Number of lines in each class				
	Res.	Mod. res.	Susc.	Segregating	Total
Wheat X *A. elongatum*	68	7	29	25	129
Wheat X *A. elongatum* stem rust res. sel.	217	42	15	7	281
Wheat X *A. elongatum* 1946 wheat-like selections	11	5	18	3	37
(Chinese X *A. elongatum*) X Chinese F_7; Canadian hybrids	3	0	0	0	3
Wheat X *A. glaucum* amphidiploid	1	0	0	0	1
Wheat X *Agropyron* miscellaneous	4	0	3	0	7
Mindum X *A. trichophorum*	61	32	28	11	132
Total	365	86	93	46	590

Part B. Wheat check rows

Varieties					
Med-Hope X Pawnee, C.I.12141	9	2	1	0	12
Kawvale-Marquillo X Kawvale-Tenmarq, C.I.12128	4	8	0	0	12
Pawnee, C.I.11669	5	6	0	0	11
Total	18	16	1	0	35

Apparently the wheat X *A. elongatum* material was not very homozygous for stem rust reaction, for segregating and susceptible lines were found. Again, however, the majority were resistant and showed little evidence of infection. The Mindum X *A. trichophorum* hybrids are evidently not so resistant as the *A. elongatum* since only 61 out of 132 lines were resistant. It has appeared that stem rust resistance has often been lost when the hybrids were backcrossed to wheat. The stem rust data concerning the Mindum X *A. trichophorum* hybrids presented in Table 5 are of interest in this respect.

Table 5. Class frequency of stem rust reactions of Mindum X *Agropyron trichophorum* hybrids.

Hybrid material	Number of lines in each class				
	Res.	Mod. res.	Susc.	Segregating	Total
Mindum X *A. trichophorum*, backcrossed to wheat once	39	14	7	2	62
Mindum X *A. trichophorum*, backcrossed to wheat twice	21	18	21	9	69
Mindum X *A. trichophorum*, backcrossed three times to wheat	1	0	0	0	1
Total	61	32	28	11	132

While the rust reaction of the wheat used as the backcross also has a decided influence on the progeny, it is evident that fewer of the second backcross progeny have retained the high resistance of the original hybrids.

Reaction of the Hybrids to Speckled Leaf Blotch of Wheat. Susceptible wheat varieties in 1948 showed very high field infection with speckled leaf blotch of wheat. The *Triticum-Agropyron* material, in general, appeared to have a low rate of infection. Therefore, 34 of the lines showing the most leaf rust resistance in the seedling stage and the three

Canadian hybrids received in 1947 were tested in the greenhouse for resistance to speckled leaf blotch of wheat, Septoria tritici, Rob. Results of both the spray and needle inoculations are shown in Table 6.

Of the 37 lines tested, 17 were highly resistant when subjected to the standard spray inoculation method. The highly resistant group either had no lesions or the lesions were indistinct and restricted for the most part to the leaf tips. An additional eight lines were quite resistant but segregating in the degree of resistance expressed. Three lines were moderately resistant while nine lines were nearly as susceptible as Kestar, C. I. 12110, the susceptible wheat check.

Inoculation by the needle method produced similar results for most of the lines tested. The degree of resistance was not quite as high, however, when this method was employed. Damage to tissue from the needle punctures also may be a factor in allowing the organism to establish itself. Lines showing moderate resistance under the spray method gave susceptible readings in the needle inoculation test. Lines highly resistant under the first method were still classified as resistant when the latter method was used. Only five lines continued to give highly resistant reactions.

It would seem that the needle method is the more effective in locating the highly resistant lines. The two types of susceptibility noted by Weber (87), necrotic lesions and "green islands", were observed.

Table 6. Reactions of the hybrids to speckled leaf blotch of wheat.*

Pot no.	KSC Serial No.	Reading by spray inoculation	Reading by needle inoculation
Wheat X *A. elongatum* hybrids by W. J. Sando; 1946 wheat-like selections			
11	4731-1	M	S
12	4731-3	S	S
14	4759-2	R	M
15	4777-1	HR	R
16	4777-2	R	R
From W.J. Sando's crosses, probably Wheat X *A. elongatum*			
7	45 TXA 13-453	S	S
8	45 TXA 13-466	Sr	Sr
1	45 TXA 16-489	S	S
2	45 TXA 16-491	S	M
4	45 TXA 16-492	HR	HR
5	45 TXA 16-493	S	S
3	45 TXA 18	S	S
9	45 TXA 19	HR	R
10	45 TXA 23	HR	M
6	45 TXA 30	HR	R
20	45 TXA 50	HR	R
23	45 TXA 52	HR	M
24	45 TXA 52	HRs	HRs
Canadian hybrids from T. M. Stevenson			
21	45 TXA 76 (Kharkov X *A. elongatum*)	HR	R
Wheat X *A. glaucum* hybrids, Canadian			
26	45 TXA 72	S	S
22	45 TXA 77	HR	HR
(Chinese X *A. elongatum*) X Chinese F_7			
17	S-44-6	R	R
18	S-44-2-7	HR	Rs
19	S-49-5	HR	R

Table 6. (concl.).*

Pot no.	KSC Serial No.	Reading by spray inoculation	Reading by needle inoculation
	W. J. Sando hybrids, *Agropyron* parent not specified		
27	45 TXA 87	HRm	HR
28	45 TXA 91	HR	R
29	45 TXA 95	R	M
30	45 TXA 100	HR	R
31	45 TXA 101	HR	R
32	45 TXA 103	HR	R
33	45 TXA 105	R	M
34	45 TXA 106	HR	HR
35	45 TXA 109	HR	HR
36	45 TXA 110	M	S
37	45 TXA 111	M	Ms
38	45 TXA 113	Rm	Sr
39	45 TXA 114	Sr	S
13	Westar, C.I. 12110 Susceptible check	S	S
40	Westar, C.I. 12110 Susceptible check	S	S
25	Nabob C.I. 8869 Res. check	HR	HR

* HR - Near immunity
R = Occasional lesion
M = Slight resistance
S = Susceptible
In segregating lines capitals indicate predominant group.

In an additional test, five *Agropyron* species, *elongatum* *trichophorum*, *glaucum*, *intermedium*, and *smithii*, all gave zero readings when the spray inoculation method was used. Four Westar checks gave susceptible readings. The immunity of these Agropyron species to infection by *Septoria tritici*, Rob., is evident. The high degree of resistance possessed by the *Agropyron* parents appears to be readily transmitted to their hybrid progeny. The hybrid material provides a new source of resistance to this disease.

Reaction to Other Diseases. Natural bunt, *Tilletia* species, infection in the wheat X *A*. *elongatum* group, 1946 rows 4663-4803, was reported by Patterson (44). In 1948, no bunt infection was evident; therefore, it appears that under field conditions in Kansas, the hybrid material cannot be too susceptible since the infection present in 1946 had disappeared by 1948. A bunt nursery established in 1947 failed to give any bunt readings. In order to test this further, 171 of the most rust resistant lines were bunted and planted in the 1949 disease nursery.

The *Triticum*-*Agropyron* nursery has been isolated from the wheat breeding nursery; this has given little chance for natural loose smut, *Ustilago tritici*, infection in the hybrid material. Med-Hope X Pawnee, C.I. 12141, susceptible to loose smut, however, has been used as a wheat check in the *Triticum*-*Agropyron* nursery. It could have served as an inoculum carrier. Two lines of the hybrid material had a low rate of infection. In order to test for loose smut reactions, a total of 629 heads from 81 leaf rust resistant lines were inoculated in the 1948 nursery and seeded in the 1949 wheat breeding nursery.

In 1947, ergot, *Claviceps* species, was present in the hybrid population in varying amounts. The wheat X *A. elongatum* group, 1946 rows 4664-4803, had ergot counts raning from zero to 30 per cent with an average of approximately 2.3 per cent. The remaining hybrids showed a much higher rate of ergot infection with percentages of 5, 10, and 20 occurring most frequently. The maximum, 90 per cent, occurred in a Mindum X *A. trichophorum* hybrid. These hybrids generally had high infection rates, 50 per cent being observed in a number of lines. Wheat X *A. glaucum* amphidiploids also had infection percentages of 50 to 60.

Ergot infection in 1948 dropped considerably from the high 1947 rate even though the nursery was reestablished on the same plot that it had occupied in 1947. The maximum infection, 10 per cent, occurred in a wheat X *A. glaucum* amphidiploid. In 1222 lines examined, 12 had an infection of one per cent, four had two per cent, and one had five per cent. This appeared to be representative of the hybrid material in the 1948 nursery.

The smaller incidence of infection could have been ascribed to two factors - drier weather conditions during blossoming time and increased fertility of the hybrids. The Canadian workers generally have stated that they believed the incidence of infection would be reduced as fertility was increased. Seed planted in the 1948 nursery was partly selected on the basis of plumpness and seed size. This may have been instrumental in selecting for more fertile lines, for Thompson (73) noted that seed shriveling often indicates chromosome unbalance.

Brown necrosis or melanism was noticed on many of the hybrids in the field. McFadden (37) states that this is not a disease in itself but rather a type of reaction to rust, especially stem rust, when the plant shows the mature-plant type of resistance. Pentad, Hope, and H-44 wheats and their hybrids are especially affected in this way. The condition is aggravated by long periods of high light intensities. The many X-type readings obtained in seedling tests could possibly be associated with brown necrosis in the field.

Variation for mildew reaction was noticed in the lines used for the Septoria test. Infection persisted in some lines despite the use of sulfur dusts. Other lines did not show any infection at all.

Sharp difference in aphid resistance was also noted in the same material. Line 4759-2, wheat X A. elongatum, in pot number 14, was free from aphids while the material in surrounding pots was heavily infested. Many of the other lines also were free of aphids, but the distinction was not as evident.

Agronomic Characters

Winterhardiness. The winters of 1946-47 and 1947-48 were moderate; snow covering was present during the coldest periods. In the wheat breeding nursery, winterkilling was not evident except in a few rows of material with very limited winterhardiness.

Winter survival of the material in the 1947 wheat X *Agropyron* nursery is given in Tables 7 and 8. Readings are based on dead plant counts and comparisons with the wheat checks. Some of the rows were badly damaged by washing early in the spring. These are not included in the survival data. Varying totals for the same groups in other tables are due to inclusion or exclusion of these rows.

The 1947 nursery was composed mostly of bulk material. Winterkilling differences would not be so noticeable in such material as in plant-selected materials. The annual, wheat X *Agropyron elongatum* group shows the severest winterkilling. Some spring wheats, especially Federation, C. I. 4734, are known to be present in the wheat parentage and could have contributed to the loss of winterhardiness in the annual group.

Less winterhardy segregates apparently are present in much of the bulk material, as evidenced by some winterkilling in most of the material in only a moderate winter.

The material in the three-foot rows, Table 8, is noticeably more susceptible to winterkilling than the eight-foot-row

Table 7. Frequency distribution of winter survival percentage in wheat X *Agropyron* hybrids, 1947 nursery, eight-foot rows.

Hybrid material	Number of lines in each percentile group 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	Total	Mean
Wheat X *A. elongatum* more-or-less perennial	0	0	0	0	1	0	2	3	0	69	75	97.73
Wheat X *A. elongatum* annual	8	1	0	1	2	2	7	5	9	21	56	73.79
Wheat X *A. trichophorum* more-or-less perennial	0	0	0	0	0	0	0	0	0	2	2	100.00
Wheat X *A. glaucum* more-or-less perennial	0	0	0	0	0	0	0	0	0	1	1	100.00
Wheat X *A. glaucum* annual	0	0	0	0	0	0	0	0	0	4	4	100.00
Miscellaneous, annual Wheat X *Agropyron* parent not specified	0	0	0	0	0	1	0	0	2	33	33	95.56
Total	8	1	0	1	3	3	9	8	11	130	174	90.24
Wheat checks:												
Kawvale-Marquillo X Kawvale-Tenmarq C.I.12128; Kanred C.I.5146; Pawnee C.I.11669; Cheyenne C.I. 8885; Med-Hope X Pawnee C.I.12141	0	0	0	0	0	0	0	0	0	15	15	100.00
Grass checks:												
A. smithii (1); *A. trichophorum* (2); *A. elongatum*(3); *A. intermedium* (2); *A. glaucum* (1); *Secale montanum* (1)	0	0	0	0	0	0	0	0	0	10	10	100.00
Total	0	0	0	0	0	0	0	0	0	25	25	100.00

Table 8. Frequency distribution of winter survival percentage in wheat X *Agropyron* hybrids, 1947 nursery, three-foot rows.

Hybrid material	Number of lines in each percentile group										Total	Mean
	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100		
Wheat X *A. elongatum* perennial	16	0	0	0	2	0	0	0	1	32	51	66.47
Wheat X *A. elongatum* annual	12	0	0	1	1	0	0	0	0	45	59	77.97
Wheat X *A. trichophorum* perennial	5	0	0	0	1	0	0	0	0	11	17	68.25
Wheat X *A. trichophorum* annual	5	2	0	0	2	0	0	0	0	10	19	61.05
Miscellaneous												
Wheat X *Agropyron* perennial	1	0	0	0	0	0	0	0	0	10	11	90.91
Total	39	2	0	1	6	0	0	0	1	108	157	72.04
Wheat checks: Kawvale-Marquillo X Kawvale-Tenmarq. C.I.12128 Kanred C.I.5146 Med-Hope X Pawnee C.I.12141 Pawnee C.I.11669 Cheyenne C.I.8885	0	0	0	0	0	0	0	0	0	15	15	100.00

material, Table 7. This has been due partly to differences in rate of sowing.

Taken as a group, the wheat X Agropyron material is not so winterhardy as the winter wheat checks, three of which, Pawnee, Kanred, and Cheyenne, are well adapted in winterhardiness to the Kansas hard red winter wheat area. The material was not analyzed statistically for differences in survival between annual and more-or-less perennial lines.

The material in the eight-foot rows of the 1948 nursery, Table 9, is composed entirely of the better lines present and harvested in the 1947 nursery. Survival values vary but slightly.

The three-foot-row material of the 1948 nursery, Table 10, consisted of head selections from the better 1947 three-foot-row lines, rust resistant plant selections of the wheat X A. elongatum hybrid material (1946 rows 4664-4803) tested in the greenhouse, wheat-like selections made in 1946 from the same material, and selections of Mindum X A. trichophorum backcrossed to winter wheat. Survival values were based on actual plant counts in the fall and spring. It is quite evident that the material is not so good as the wheat checks used.

Of special interest are the two groups of Mindum X A. trichophorum derivatives. Mindum, the original wheat parent, is a durum variety and not expected to be winterhardy. Winterhardiness in the original hybrids must, then, have come from the Agropyron parent. The second backcross to winter wheat has

Table 9. Frequency distribution of winter survival percentage in wheat X *Agropyron* hybrids, 1948 nursery, eight-foot rows.

Hybrid material	Number of lines in each percentile group											
	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	Total	Mean
Wheat X *A. elongatum*	0	0	0	0	0	0	0	2	5	74	81	98.70
Wheat X *A. trichophorum*	0	0	0	0	0	0	0	1	0	4	5	95.40
Wheat X *A. glaucum*	0	0	0	0	0	0	0	0	0	3	3	100.00
Wheat X *Agropyron*	0	0	0	0	0	0	0	0	3	28	31	98.71
Total	0	0	0	0	0	0	0	3	8	109	120	98.60
Wheat checks: Pawnee C.I.11669 Med-Hope X Pawnee C.I.12141 Kawvale-Marquillo X Kawvale-Tenmarq. C.I.12128	0	0	0	0	0	0	0	0	0	15	15	100.00

Table 10. Frequency distribution of winter survival percentage in wheat X *Agropyron* hybrids, 1948 nursery, three-foot rows.

Hybrid material	Number of lines in each percentile group											
	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	Total	Mean
Wheat X *A. elongatum* 1947 rust resistant selections	2	3	2	10	10	27	38	51	42	73	258	75.73
Wheat X *A. elongatum* wheat-like selections 1946	2	0	2	1	2	0	4	4	2	21	38	78.83
Wheat X *A. elongatum* bulks	3	2	6	5	8	10	19	16	24	35	128	71.93
Mindum X *A. trichophorum* 1st backcross to wheat	5	9	13	44	13	6	7	4	2	2	64	41.57
Mindum X *A. trichophorum* 2nd backcross to wheat	7	4	1	2	3	4	6	4*	6	25	62	68.00
Wheat X *A. glaucum*	1	0	0	0	1	1	0	0	0	0	3	33.66
Wheat X *Agropyron* miscellaneous	8	1	0	1	0	0	1	1	0	2	14	29.21
Total	28	19	24	23	36	48	75	80	76	158	567	69.01
Wheat checks: Pawnee C.O.11669 Med-Hope X Pawnee C.I.12141 Kawvale-Marquillo X Kawvale-Tenmarq C.I.12128	0	0	0	0	0	1	0	0	3	29	33	96.00

* Contains one line of Mindum X *A. trichophorum* backcrossed to wheat three times.

raised the survival percentage considerably. The difference appears to be significant.

Two contributing factors must also be taken into a consideration of the results obtained in the 1948 nursery. Suneson and Pope (72) state that nitrogen appears to be a limiting factor in winter survival. The protein relationship to winterhardiness also has been stressed by the Russian workers (77). Due to dry weather conditions, the plowed-under stubble of the previous nursery had hardly begun to decompose by the time the 1948 crop was seeded. This probably established a wide carbon-nitrogen ratio in the soil, setting up a nitrogen deficiency as indicated by yellowed seedlings which were very much in evidence in the fall of 1947. The development of the seedlings was further retarded by a lack of moisture in the fall. Many did not tiller before winter set in. Kovaleva (30) states that the Triticum-Agropyron hybrids are not winterhardy until well past the two to three leaf stage. Therefore, both of the factors listed could have contributed to reduced survival.

The hybrids, except in a few cases, did not appear as vigorous as the wheat checks at any time. Wheat parentage, a probable nitrogen deficiency, and retarded development were, possibly, the chief factors controlling survival variation.

Fall Regrowth. In order to study fall regrowth and perennial tendencies, the section of the 1947 nursery containing the more-or-less perennial wheat X *A. elongatum* hybrids was not disturbed. Regrowth notes were taken on September 8, 1947, and again on November 21, 1947. The number of plants in each row containing perennial plants at those dates is given in Table 11. Thirty-seven rows in this group had no plants at either date. The highest number of plants in any one row at the first reading was 69, and on the second, 24 plants. The average number of plants per row in the lines showing some perennial tendencies at the first reading was 9.76. At the second date this had been reduced to 4.74 plants per row. Only 48.6 per cent of the number of plants seen on the earlier date were still alive on November 21, 1947. A check in the spring of 1948 indicated that most of the remaining plants had died during the winter.

One line of wheat X *A. trichophorum* hybrid material had 12 plants on the first date and seven on the second reading. A second line had no regrowth at either date. No regrowth was noted in the one line of wheat X *A. glaucum* included in this group.

At best, only limited perennialism is indicated by the material studied in this project.

Height. The very wide range of the heights of the hybrid is evident in Tables 12, 13, and 14. In 1947, Table 12, the wheat checks had a height range of 37 to 45 inches, the grass checks, 18 to 42 inches, and the hybrid material, 25 to 53 inches. Approximately 30 per cent of the hybrids were taller

Table 11. Fall regrowth of more-or-less perennial wheat X *Agropyron elongatum* hybrids, 1947 nursery.

1947 Row no.	Plants per row 9/8/47	Plants per row 11/21/47	1947 Row no.	Plants per row 9/8/47	Plants per row 11/21/47
6	2	0	26	18	9
7	29	20	28	2	2
8	25	15	29	24	13
9	1	0	31	1	0
10	1	0	32	3	2
11	3	2	38	1	1
12	0	1	39	1	1
13	1	0	41	0	2
14	2	0	56	1	1
15	69	24	59	1	5
16	25	13	60	21	5
17	18	7	61	7	1
18	22	9	67	9	2
19	1	2	76	0	1
21	1	0	79	0	1
22	20	12	89	1	0
23	20	9	90	1	0
24	33	20	91	4	0
25	7	5	92	2	0
			94	4	0

Total number of plants, 9/8/47: 381.

Total number of plants, 11/21/47: 185.

Per cent surviving, 11/21/47: 48.6.

than the tallest wheat check; 60 per cent had heights within the range of the wheat checks, and 10 per cent were shorter. The average hybrid was about two inches taller than the average wheat check.

The 1948 heights are generally shorter than those of 1947. In the eight-foot rows, Table 13, the range of the wheat checks is from 27 to 35 inches with an average of 31.14 inches - the two tall wheat checks of 1947, Kanred and Cheyenne,were not used. The hybrid group had a range of 23 to 45 inches and an average height of 35.52 inches. Approximately 50 per cent of the hybrids were taller than the tallest wheat check; most of the others were in the range of the wheat checks.

In the 1948 three-foot-row material, Table 14, the hybrid range was from 12 to 46 inches as compared to the 29 to 36 inch range of the wheat checks. Only about 16 per cent were taller than the tallest wheat checks; 51 per cent of the hybrid heights were in the range of the wheat checks, while one-third were shorter. The average heights of the hybrids and wheat checks, however, are much the same.

Most of the hybrid material is well within the height range of the wheat checks used. Taller and shorter material was abundant, however.

Table 12. Distribution of the heights of wheat X *Agropyron* hybrids, 1947 nursery, eight-foot rows.

Number of rows in each height interval

Height inches	Hybrid material							Wheat checks	Grass checks
	Wheat X *A.* *elongatum* perennial	Wheat X *A.* *elongatum* annual	Wheat X *A.* *trichophorum* perennial	Misc. annual	Wheat X *A.* *glaucum* perennial	Wheat X *A.* *glaucum* annual	Total		
53	0	0	0	0	0	2	2	0	0
52	2	0	0	0	0	0	2	0	0
51	1	0	0	0	0	0	1	0	0
50	3	0	0	0	0	1	4	0	0
49	5	0	0	0	0	0	5	0	0
48	6	0	0	5	0	0	11	0	0
47	4	2	0	2	0	1	9	0	0
46	8	3	0	7	0	0	18	0	0
45	7	6	0	3	0	0	16	1	0
44	11	1	0	1	0	0	13	2	0
43	6	8	1	3	1	0	19	1	0
42	5	9	0	1	0	0	15	2	1[3]
41	3	7	0	5	0	0	15	4	0
40	4	2	0	3	0	0	9	0	1[5]
39	1	3	0	2	0	0	6	3	1[3]
38	1	3	1	0	0	0	5	0	1[6]
37	2	5	0	2	0	0	9	2	0
36	1	2	0	0	0	0	3	0	0
35	0	1	0	2	0	0	3	0	0
34	0	0	0	0	0	0	0	0	1[4]
33	0	0	0	0	0	0	0	0	0
32	1	0	0	0	0	0	1	0	0
31	3	2	0	0	0	0	5	0	0
30	0	0	0	0	0	0	0	0	0
29	0	1	0	0	0	0	1	0	0
28	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	2[2,4]
26	1	0	0	0	0	0	1	0	0
25	0	1	0	0	0	0	1	0	1[2]
24	0	0	0	0	0	0	0	0	0

Table 12. (concl.).

Height inches	Hybrid material: Wheat X *A. elongatum* perennial	Wheat X *A. elongatum* annual	Wheat X *A. trichophorum* perennial	Misc. annual	Wheat X *A. glaucum* perennial	Wheat X *A. glaucum* annual	Total	Wheat checks	Grass checks
23	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	1^1
19	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	1^2
Total no. of rows	75	56	2	36	1	4	174	15	10
Av. ht. inches	43.76	40.61	40.5	43.14	43.0	50.8	42.74	40.9	31

Wheat checks: Kawvale-Marquillo X Kawvale-Tenmarq, C.I.12128
Mod-Hope X Pawnee, C.I.12141
Kanred, C.I.5146
Cheyenne, C.I.8885
Pawnee, C.I.11669

Grass checks: 1 *A. smithii*; 2 *A. elongatum*; 3 *A. intermedium*; 4 *A. trichophorum*;
5 *A. glaucum*; 6 *Secale montanum*.

Table 13. Distribution of the heights of wheat X *Agropyron* hybrids, 1948 nursery, eight-foot rows.

No. of rows in each height interval

Height inches	Hybrid material					Wheat checks
	Wheat X *A.* *elongatum*	Wheat X *A.* *trichophorum*	Wheat X *A.* *glaucum*	Misc.	Total	
45	0	0	0	2	2	0
44	0	0	0	1	1	0
43	1	0	2	0	3	0
42	7	0	0	3	10	0
41	2	0	0	0	2	0
40	1	0	0	2	3	0
39	2	0	0	2	4	0
38	6	0	1	2	9	0
37	4	0	0	2	6	0
36	16	0	0	4	20	0
35	10	1	0	4	15	1
34	9	0	0	5	14	1
33	6	1	0	1	8	3
32	7	0	0	1	8	0
31	6	2	0	0	8	3
30	1	0	0	2	3	4
29	2	0	0	0	2	0
28	1	0	0	0	1	1
27	0	0	0	0	0	1
26	2	0	0	0	2	0
25	0	0	0	0	0	0
24	0	1	0	0	1	0
23	0	1	0	0	1	0
Total no. of rows	83	6	3	31	123	14
Av. ht. inches	35.19	29.50	41.33	37.0	35.52	31.14

Wheat checks: Kawvale-Marquillo X Kawvale-Tenmarq, C.I.12128
Med-Hope X Pawnee, C.I.12141
Pawnee, C.I.11669

Table 14. Distribution of the heights of wheat X Agropyron hybrids, 1948 nursery, three-foot rows.

	Hybrid material							
Height inches	Wheat X A. elongatum 1947 rust res. sel.	Wheat X A. elongatum 1946 wheat-like sel.	Wheat X A. elongatum bulks	Mindum X A. trichophorum 1st bc.	Mindum X A. trichophorum 2nd bc.	Misc.	Total	Wheat checks
	Number of rows in each height interval							
46	0	0	1	0	0	0	1	0
45	0	0	0	0	0	0	0	0
44	0	0	1	1	0	0	2	0
43	0	0	1	1	0	0	2	0
42	4	3	1	0	0	0	8	0
41	2	0	6	1	0	0	9	0
40	10	1	11	0	1	1	24	0
39	3	2	5	0	0	0	10	0
38	6	2	6	1	0	0	15	0
37	13	3	9	1	0	0	26	0
36	12	2	7	2	4	0	27	3
35	23	3	6	2	1	0	35	2
34	20	1	5	3	5	1	35	4
33	28	5	6	2	6	1	48	1
32	19	3	8	1	7	0	38	9
31	19	1	8	2	4	0	34	10
30	21	0	12	3	7	0	43	2
29	22	1	7	3	7	1	41	4
28	13	3	7	3	6	0	32	0
27	15	0	4	5	4	0	28	0
26	7	1	7	0	6*	0	21	0
25	9	0	3	2	3	0	17	0
24	6	1	2	6	3	0	18	0
23	7	0	1	4	1	0	13	0
22	3	0	1	3	1	1	9	0
21	5	0	1	5	4	3	18	0
20	4	0	0	0	0	0	4	0
19	2	0	2	0	0	0	4	0

Table 14. (concl.).

Height	Hybrid material							
	Wheat X *A.* *elongatum*	Wheat X *A.* *elongatum*	Wheat X *A.*	Mindum X *A.* *trichophorum*				
inches	1947 rust res. sel.	1946 wheat-like sel.	*elongatum* bulks	1st bc.	2nd bc.	Misc.	Total	Wheat checks
18	2	2	1	3	0	0	8	0
17	1	0	1	1	0	0	3	0
16	4	1	0	1	0	0	6	0
15	0	2	0	0	0	0	2	0
14	2	0	0	1	0	0	3	0
13	1	0	0	1	0	0	2	0
12	0	0	0	0	1	0	1	0
Total no. of rows	283	37	130	58	71	8	587	35
Av. ht. inches	31.13	31.86	32.78	27.14	29.13	27.63	30.68	32.03

Wheat checks: Kawvale-Marquillo X Kawvale-Tenmarq, C.I.12128
Med-Hope X Pawnee, C.I. 12141
Pawnee, C.I. 11669

" = Wheat X *A.* *glaucum* amphidiploid.

* Includes one line of Mindum X *A.* *trichophorum*, 3rd bc.

Heading Date. Since the farmer demand has been for earlier wheat varieties, the heading date of wheat breeding material is of much importance. The average heading date of the wheat X *Agropyron* hybrid material in the 1947 nursery, Tables 17 and 18, is considerably later than the average heading date of the wheat checks used. Pawnee, C. I. 11669, a fairly early variety considered to have about the ideal heading time for much of Kansas, headed on May 22 in 1947, and one day earlier in 1948. Very little of the hybrid material headed as early as Pawnee. Rows were considered headed when 75 per cent of the heads were out of the boot.

The earliest heading date recorded in the eight-foot-row material in 1947, Table 15, was May 20; the last line headed on the 12th of June. The average heading date was May 31. The wheat checks headed from May 19 through the 25th with the 22nd as the average date. None of the hybrids headed earlier than the wheat checks; 30 per cent headed within the heading date range of the checks, leaving 70 per cent with a much later heading date. Most of these headed about one week later than the last date recorded for any of the wheat checks. Two of the wheat checks, Kanred and Cheyenne, are not considered early wheats.

In the three-foot rows of the 1947 nursery, Table 16, approximately 89 per cent of the hybrids headed later than any of the wheat checks, 10 per cent within the range of the checks, and 1 per cent were earlier. Heading dates of the

Table 15. Distribution of heading dates of wheat X *Agropyron* hybrids, 1947 nursery, eight-foot rows.

No. of rows headed at each date

	Hybrid material							
Heading date	Wheat X *A.* *elongatum* perennial	Wheat X *A.* *elongatum* annual	Wheat X *A.* *trichophorum* perennial	Misc. annual	Wheat X *A.* *glaucum* perennial	Wheat X *A.* *glaucum* annual	Total	Wheat checks
5-19	0	0	0	0	0	0	0	1
5-20	0	2	0	0	0	0	2	3
5-21	3	2	0	1	0	0	6	2
5-22	3	1	0	0	0	0	4	1
5-23	8	2	0	0	0	0	10	1
5-24	5	3	1	0	0	0	9	1
5-25	8	8	1	2	0	0	19	1
5-26	1	3	0	1	0	0	5	0
5-27	5	2	0	8	0	0	15	0
5-28	2	0	0	2	0	0	4	0
5-29	0	0	0	0	0	0	0	0
5-30	0	0	0	0	0	0	0	0
5-31	0	1	0	0	0	0	1	0
6- 1	4	6	0	3	0	0	13	0
6- 2	3	2	0	0	0	0	5	0
6- 3	8	5	0	4	1	0	18	0
6- 4	3	0	0	0	0	0	3	0
6- 5	5	5	0	8	0	1	19	0
6- 6	1	4	0	1	0	0	6	0
6- 7	7	3	0	3	0	0	13	0
6- 8	2	3	0	1	0	0	5	0
6- 9	1	2	0	1	0	1	5	0

Table 15. (concl.).

Heading date	Hybrid material							Wheat checks
	Wheat X *A.* *elongatum* perennial	Wheat X *A.* *elongatum* annual	Wheat X *A.* *trichophorum* perennial	Misc. annual	Wheat X *A.* *glaucum* perennial	Wheat X *A.* *glaucum* annual	Total	
6-10	0	1	0	0	0	0	1	0
6-11	1	0	0	0	0	1	2	0
6-12	0	0	0	1	0	1	2	0
Total no. of rows	70	54	2	36	1	4	167	10
Av. date headed	5-30	5-30	5-25	6-1	6-3	6-9	5-31	5-22

Wheat checks: Kawvale-Marquillo X Kawvale-Tenmarq, C.I.12128
Med-Hope X Pawnee, C.I.12141
Kanred, C.I.5146
Cheyenne, C.I.8885
Pawnee, C.I.11669

Agropyron intermedium headed 6-11-47

A. glaucum headed 6-9-47

Table 16. Distribution of heading dates of wheat X *Agropyron* hybrids, 1947 nursery, three-foot rows.

	Heading date	Hybrid material						Wheat checks
		Wheat X *A. elongatum* perennial	Wheat X *A. elongatum* annual	Wheat X *A. trichophorum* perennial	Wheat X *A. trichophorum* annual	Misc. perennial	Total	
No. of rows headed at each date	5-22	0	0	1	0	0	1	0
	5-23	0	0	0	0	0	0	6
	5-24	0	0	0	0	0	0	1
	5-25	0	2	0	0	0	2	0
	5-26	1	1	0	0	0	2	1
	5-27	2	1	0	0	0	3	1
	5-28	0	3	0	0	0	3	2
	5-29	0	0	0	0	0	0	0
	5-30	0	0	0	0	0	0	2
	5-31	0	0	0	0	0	0	1
	6- 1	4	3	-	7	0	14	0
	6- 2	1	4	0	0	0	5	0
	6- 3	1	7	0	0	0	8	1
	6- 4	0	1	0	0	0	1	0
	6- 5	2	7	2	2	0	13	0
	6- 6	1	0	2	0	0	3	0
	6- 7	2	1	0	1	0	4	0
	6- 8	3	3	1	0	3	10	0
	6- 9	0	6	0	0	0	6	0
	6-10	0	0	0	0	0	0	0

Table 16. (concl.).

Heading date	Hybrid material						Wheat checks
	Wheat X *A. elongatum* perennial	Wheat X *A. elongatum* annual	Wheat X *A. trichophorum* perennial	Wheat X *A. trichophorum* annual	Misc. perennial	Total	
6-11	7	0	0	0	1	8	0
6-12	3	3	0	1	2	9	0
6-13	2	4	1	0	0	7	0
Total no. of rows	29	46	7	11	6	99	15
Av. date headed	6-6	6-5	6-5	6-3	6-10	6-5	5-26

Wheat checks: Kawvale-Marquillo X Kawvale-Tenmarq, C.I.12128
Med-Hope X Pawnee, C.I.12141
Kanred, C.I.5146
Pawnee, C.I.11669
Cheyenne, C.I.8885

Table 17. Distribution of heading dates of wheat X *Agropyron* hybrids, 1948 nursery, eight-foot rows.

	Hybrid material					
Heading date	Wheat X *A.* elongatum	Wheat X *A.* trichophorum	Wheat X *A.* glaucum	Misc.	Total	Wheat checks
Number of rows headed at each date						
5-19	0	0	0	1	1	6
5-20	0	0	0	1	1	5
5-21	3	0	0	0	3	1
5-22	1	0	0	0	1	0
5-23	3	0	0	0	3	1
5-24	6	0	0	1	7	0
5-25	4	1	0	2	7	2
5-26	3	1	0	3	7	0
5-27	2	0	0	1	3	0
5-28	7	0	0	0	7	0
5-29	6	0	0	3	9	0
5-30	3	0	0	1	4	0
5-31	3	0	1	0	4	0
6- 1	8	0	0	5	13	0
6- 2	6	0	0	0	6	0
6- 3	5	0	1	4	10	0
6- 4	2	0	0	0	2	0
6- 5	2	0	0	2	4	0
6- 6	0	0	0	0	0	0
6- 7	0	0	0	4	4	0
6- 8	1	0	0	1	2	0
6- 9	2	1	0	1	4	0
6-10	1	1	0	0	2	0
6-11	4	1	0	2	7	0
6-12	3	0	0	0	3	0
6-13	2	0	0	0	2	0
6-14	0	0	0	0	0	0
6-15	0	0	0	0	0	0
6-16	6	1	1	0	8	0
6-17	0	1	0	0	1	0
6-18	1	0	0	0	0	0
Total no. of rows	84	7	3	32	126	15
Av. date heading	6-1	6-7	6-6	6-1	6-2	5-21

Wheat checks: Kawvale-Marquillo X Kawvale-Tenmarq, C.I.12128
Med-Hope X Pawnee, C.I.12141
Pawnee, C.I.11669

Grass checks remaining from 1947 nursery:

Agropyron trichophorum headed 5-26-48
Agropyron intermedium headed 6- 7-48
Agropyron glaucum headed 6- 7-48
Agropyron elongatum headed from 6-20 to 6-30-48

Table 18. Distribution of heading dates of wheat X *Agropyron* hybrids, 1948 nursery, three-foot rows.

Heading date	Hybrid material							Wheat checks
	Wheat X *A. elongatum*		Wheat X *A. elongatum*	Mindum X *A. trichophorum*				
	1947 rust-res. sel.	1946 wheat-like sel.	bulks	1st bc.	2nd bc.	Misc.	Total	
Number of rows headed at each date								
5-18	0	0	0	0	0	0	0	1
5-19	0	0	1	0	0	0	1	0
5-20	0	0	5	0	0	0	5	2
5-21	1	0	0	0	0	0	1	6
5-22	0	0	0	0	0	0	0	1
5-23	1	0	0	0	1	0	2	9
5-24	2	1	2	0	1*	0	6	6
5-25	5	7	3	0	0	0	15	5
5-26	20	4	7	2	3	1	37	2
5-27	3	3	4	0	0	0	10	1
5-28	4	0	7	0	0	0	11	1
5-29	11	1	4	3	6	0	25	1
5-30	8	0	5	1	4	1	19	0
5-31	1	2	5	0	2	0	10	0
6- 1	13	2	3	9	5	0	32	0
6- 2	1	4	6	1	1	0	13	0
6- 3	0	0	5	0	0	0	5	0
6- 4	1	1	3	1	3	0	9	0
6- 5	60	2	13	12	22	0	109[2]	0
6- 6	0	0	4	0	0	0	4	0
6- 7	26	3	14	6	10	1	60[2]	0
6- 8	12	0	6	1	4	0	23	0
6- 9	0	0	0	0	0	0	0	0
6-10	5	0	3	0	2	1	11	0
6-11	22	1	8	4	4	0	39	0
6-12	12	2	4	4	2	1	25	0
6-13	2	0	0	2	1	1	6	0
6-14	23	2	2	1	0	0	28	0
6-15	0	0	0	0	0	0	0	0

Table 18. (concl.).

Heading date	Hybrid material: Wheat X *A. elongatum* 1947 rust-res. sel.	Hybrid material: Wheat X *A. elongatum* 1946 wheat-like sel.	Hybrid material: Wheat X *A. elongatum* bulks	Hybrid material: Mindum X *A. trichophorum* 1st bc.	Hybrid material: Mindum X *A. trichophorum* 2nd bc.	Hybrid material: Misc.	Hybrid material: Total	Wheat checks
6-16	7	0	0	0	0	0	7	0
6-17	15	1	1	1	0	2[1]	20	0
6-18	11	1	1	4	1	0	18	0
6-19	2	0	1	0	0	0	3	0
6-20	4	0	6	2	0	0	12	0
6-21	2	0	2	0	0	0	4	0
6-22	5	0	2	1	0	0	8	0
6-23	0	0	0	2	0	0	2	0
6-24	1	0	0	0	0	0	1	0
Total no. of rows	280	37	127	57	72	8	581	35
Av. date headed	6-7	6-2	6-4	6-8	6-4	6-9	6-6	5-23

One wheat X *A. elongatum* (bulk) not headed on 7-6-48

Wheat checks: Kawvale-Marquillo X Kawvale-Tenmarq, C.I.12128
Med-Hope X Pawnee, C.I.12141
Pawnee, C.I.11669

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* Mindum X *A. trichophorum* backcrossed to wheat three times.

[1] One of those is a wheat X *A. glaucum* line.

[2] Nursery was not visited on 6-4 and 6-6; this accounts for large groups on 6-5 and 6-7.

hybrids extended from May 22 to June 13, with June 5 as an average. The wheat checks headed from May 23 to 31, with May 26 as an average heading date.

The hybrids in the 1948 eight-foot-row nursery, Table 17, headed over a period of about one month, extending from May 19 to June 18. Average heading date was on June 2. Approximately 18 per cent of the hybrids headed during the heading period of the wheat checks, May 19 to 24. The average heading date of the hybrid material was nearly two weeks later than the average heading date of the checks.

Similar results were obtained in the three-foot-row material in 1948, Table 18. The wheat checks headed from May 18 to 29, with May 23 as an average date. Only about 19 per cent of the hybrids headed during the same period. Heading dates of the hybrid material extended from May 19 to June 24, with June 6 as the average heading date.

It is obvious that only a small percentage of the hybrids have the desired early heading and that most of the material is too late as it now stands. This suggests the need for further backcrossing and selection to establish an acceptable degree of earliness.

Yield. Yields of the 1947 wheat X *Agropyron* hybrid material are compared with the wheat check yields in Table 19 and a similar comparison for 1948 is presented in Table 20. The average yield for each group of material was not calculated.

In 1947, approximately 4 per cent of the hybrids yielded above 35 bushels per acre, while approximately 83 per cent did not yield above 25 bushels an acre. Meanwhile, 9 out of the 10 wheat checks yielded from 31 to 55 bushels an acre.

In 1948, the hybrid yields were lower than in 1947. This was partly due to the fact that selection for rust resistance had been exercised; since many of the higher-yielding hybrids in 1947 were rust susceptible, they were not seeded in 1948. This helped to reduce the number of high-yielding hybrid lines. An occasional high-yielding hybrid line was observed, however.

Thus, in general, the hybrids do not yield very well in comparison with the wheat checks. If later observations prove that the few high-yielding hybrids have also retained the desirable *Agropyron* characters, then real progress has been made.

Test Weights. The estimated test weights per bushel of the wheat X *Agropyron* hybrids are compared with the wheat checks in Tables 21 and 22. In 1947, Table 21, nearly all of the estimated test weights of the hybrids ranged from 52 to 58 pounds per bushel, with most of them in the 55, 56, and 58 pound range. The wheat checks averaged 60 pounds per bushel.

In 1948, the largest group of estimated test weights lay in the 47 to 53 pounds per bushel range. This compares with the estimated test weights of 59 pounds and above for the

Table 19. Distribution of yields per acre of wheat X *Agropyron* hybrids, eight-foot rows, 1947 nursery.

Hybrid material	Number of rows in each class interval (bushels per acre)											Total
	0-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	
Wheat X *A. elongatum* perennial	5	7	8	17	21	9	3	1	1	1	0	73
Wheat X *A. elongatum* annual	11	4	10	12	7	3	3	0	0	0	0	50
Wheat X *A. trichophorum* perennial	0	0	2	0	0	0	0	0	0	0	0	2
Wheat X *Agropyron* misc. annual	6	10	5	7	3	0	1	2	1	0	0	35
Wheat X *A. glaucum* perennial	0	0	0	0	0	1	0	0	0	0	0	1
Wheat X *A. glaucum* annual	2	2	0	0	0	0	0	0	0	0	0	4
Total	24	23	25	36	31	13	7	3	2	1	0	165
Wheat checks	0	0	0	1	0	0	2	2	1	2	2	10

Wheat checks: Kawvale-Marquillo X Kawvale-Tenmarq, C.I.12128
Med-Hope X Pawnee, C.I.12141
Kanred, C.I.5146
Cheyenne, C.I.8885
Pawnee, C.I.11669

Table 20. Distribution of yields per acre of wheat X *Agropyron* hybrids, eight-foot rows, 1948 nursery.

Hybrid material	Number of rows in each class interval (bushels per acre)													Total
	0 to 5	6 to 10	11 to 15	16 to 20	21 to 25	26 to 30	31 to 35	36 to 40	41 to 45	46 to 50	51 to 55	56 to 60	61 to 65	
Wheat X *A. elongatum*	16	15	21	20	10	1	1	0	1	0	0	0	0	85
Wheat X *A. trichophorum*	3	1	1	0	0	0	0	0	0	0	0	0	0	5
Wheat X *A. glaucum*	1	0	2	0	0	0	0	0	0	0	0	0	0	3
Wheat X *Agropyron* misc.	10	6	7	4	2	0	0	0	0	0	0	0	0	29
Total	30	22	31	24	12	1	1	0	1	0	0	0	0	122
Wheat checks	0	0	0	1	1	1	1	1	1	3	2	3	1	15

Wheat checks: Kawvale-Marquillo X Kawvalo-Tenmarq, C.I.12128
Med-Hope X Pawnee, C.I.12141
Pawnee, C.I.11669

Table 21. Distribution of estimated test weights per bushel, wheat X Agropyron hybrids, eight-foot rows, 1947 nursery.

Hybrid material	Number of rows in each test weight per bushel interval																					
	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	Total
Wheat X A. elongatum perennial	1	0	0	0	0	0	0	0	0	0	4	0	7	2	4	13	17	18	7	0	0	73
Wheat X A. elongatum annual	0	0	0	0	0	0	0	0	0	0	1	0	2	3	6	7	6	8	8	8	1	50
Wheat X A. trichophorum perennial	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2
Wheat X Agropyron misc. annual	1	0	0	0	0	0	0	0	0	0	6	0	7	5	0	8	1	3	1	1	2	35
Wheat X A. glaucum perennial	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Wheat X A. glaucum annual	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	1	0	0	0	0	4
Total	2	0	0	0	0	0	0	0	0	0	13	0	17	10	10	29	27	29	16	9	3	165
Wheat checks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	10

Wheat checks:
Kawvale-Marquillo X Kawvale-Tenmarq, C.I.12128
Med-Hope X Pawnee, C.I.12141
Kanred, C.I.5146
Cheyenne, C.I.8885
Pawnee, C.I.11669

Table 22. Distribution of estimated test weights per bushel, wheat X *Agropyron* hybrids, eight-foot rows, 1948 nursery.

Est. test wt.	Hybrid material					Wheat checks
	Wheat X *A.* *elongatum*	Wheat X *A.* *trichophorum*	Wheat X *A.* *glaucum*	Miscel-laneous	Total	
62	0	0	0	0	0	2
61	0	0	0	0	0	4
60	0	0	0	0	0	4
59	0	0	0	0	0	3
58	0	0	0	0	0	2
57	3	0	0	0	3	0
56	4	1	0	1	6	0
55	3	0	1	0	4	0
54	4	0	0	0	4	0
53	18	0	0	1	19	0
52	6	0	0	1	7	0
51	7	0	0	0	7	0
50	6	0	0	1	7	0
49	8	0	0	4	12	0
48	2	0	0	2	4	0
47	7	1	0	4	12	0
46	4	1	0	1	6	0
45	1	0	0	2	3	0
44	0	0	0	0	0	0
43	1	0	0	1	2	0
42	2	0	0	3	5	0
41	2	0	0	1	3	0
40	2	0	0	0	2	0
39	1	0	0	0	1	0
38	0	0	0	1	1	0
37	0	1	1	0	2	0
36	3	0	1	2	6	0
35	0	0	0	0	0	0
34	1	0	0	1	2	0
33	0	0	0	1	1	0
32	0	0	0	0	0	0
31	0	0	0	0	0	0
30	0	0	0	1	1	0
29	0	1	0	0	1	0
28	0	0	0	1	1	0
Total	85	5	3	29	122	15

Wheat checks: Kawvale-Marquillo X Kawvale-Tenmarq, C.I.12128
Med-Hope X Pawnee, C.I.12141
Pawnee, C.I.11669

wheat checks. Again, many of the wheat-like hybrids that had the higher test weights in 1947 were not seeded in the 1948 nursery.

The difficulty of combining the rust resistance of the *Agropyron* species with the yield and high test weights of wheat is emphasized.

Threshing Characteristics. Difficulty in threshing was encountered in some of the hybrid material. The threshing percentages in Tables 23 and 24 represent the amount of grain obtained in the first run through a large nursery thresher in comparison with the total amount obtained; the total was composed of the amount obtained in the first-run threshing plus the quantity obtained when the tailings were run through a small head thresher.

The results indicate that some difficulty in threshing was encountered in a majority of the lines. Since most of this material represents bulks, it is probable that easy-threshing lines could be selected out of most of the material. The fact that so many of the hybrids do thresh relatively easily is an exceptional feature in the material.

For milling purposes, the grain should be free of adhering glumes. Therefore, the clean-threshing percentages presented in Tables 25 and 26 are of some interest. A visual estimate of the grain samples indicated that most of the grain is free threshing. This is, of course, a highly desirable character. Again, however, it should be emphasized that these

Table 23. Distribution of threshing percentages of wheat X *Agropyron* hybrids, eight-foot rows, 1947 nursery.

Hybrid material	Number of rows in each threshing percentile interval -60	61-65	66-70	71-75	76-80	81-85	86-90	91-95	96-100	Total
Wheat X *A. elongatum* perennial	3	2	4	9	4	11	16	15	9	73
Wheat X *A. elongatum* a annual	0	0	1	2	0	2	1	8	34	48
Wheat X *A. trichophorum* perennial	0	0	1	0	1	0	0	0	0	2
Wheat X *Agropyron* misc. annual	2	1	2	9	1	4	6	2	8	35
Wheat X *A. glaucum* perennial	0	0	0	0	0	1	0	0	0	1
Wheat X *A. glaucum* annual	2	0	1	0	0	0	0	0	1	4
Total	7	3	9	20	6	18	23	25	52	163
Wheat checks	0	0	0	0	0	0	0	1	9	10

Wheat checks: Kawvale-Marquillo X Kawvale-Tenmarq, C.I.12128
Med-Hope X Pawnee, C.I.12141
Kanred, C.I.5146
Cheyenne, C.I.8885
Pawnee, C.I.11669

Table 24. Distribution of threshing percentages of wheat X *Agropyron* hybrids, eight-foot rows, 1948 nursery.

Hybrid material	Number of rows in each threshing percentile interval									
	-60	61-65	66-70	71-75	76-80	81-85	86-90	91-95	96-100	Total
Wheat X *A. elongatum*	0	0	2	2	13	9	14	12	32	84
Wheat X *A. trichophorum*	1	0	1	1	1	1	0	0	0	5
Wheat X *A. glaucum*	0	0	1	0	1	0	1	0	0	3
Wheat X *Agropyron* misc.	0	2	1	6	8	5	1	3	3	29
Total	1	2	5	9	23	15	16	15	35	121
Wheat checks	0	0	0	0	0	0	0	0	15	15

Wheat checks: Kawvale-Marquillo X Kawvale-Tenmarq, C.I.12128
Med-Hope C Pawnee, C.I.12141
Pawnee, C.I.11669

Table 25. Distribution of the clean threshing percentages of the grain of wheat X *Agropyron* hybrids, eight-foot rows, 1947 nursery.

Hybrid material	No. of lines in each clean threshing percentile group									
	20	30	40	50	60	70	80	90	100	Total
Wheat X *A.* *elongatum* perennial	0	1	3	7	1	7	14	32	8	73
Wheat X *A.* *elongatum* annual	0	0	0	1	0	1	1	11	36	50
Wheat X *A.* *trichophorum* perennial	0	0	0	0	0	0	2	0	0	2
Wheat X *Agropyron* misc. annual	1	2	2	4	4	6	6	6	4	35
Wheat X *A.* *glaucum* perennial	0	0	0	0	0	0	0	1	0	1
Wheat X *A.* *glaucum* annual	0	0	1	1	0	1	1	0	0	4
Total	1	3	6	13	5	15	24	50	48	165
Wheat checks	0	0	0	0	0	0	0	0	10	10

Wheat checks: Kawvale-Marquillo X Kawvale-Tenmarq, C.I.12128
Med-Hope X Pawnee, C.I.12141
Kanrod, C.I.5146
Cheyenne, C.I.8885
Pawnee, C.I.11669

Table 26. Distribution of the clean threshing percentages of the grain of wheat X *Agropyron* hybrids, eight-foot rows, 1948 nursery.

Hybrid material	No. of lines in each clean threshing percentile group									
	60	65	70	75	80	85	90	95	100	Total
Wheat X *A. elongatum*	1	0	0	4	2	6	24	27	20	84
Wheat X *A. trichophorum*	1	0	1	1	0	0	1	1	0	5
Wheat X *A. glaucum*	0	1	0	1	0	0	0	1	0	3
Wheat X *Agropyron* misc.	0	1	0	3	4	3	11	6	2	30
Total	2	2	1	9	6	9	36	35	22	122
Wheat checks	0	0	0	0	0	0	0	0	15	15

Wheat checks: Kawvale-Marquillo X Kawvale-Tenmarq, C.I.12128
Med-Hope X Pawnee, C.I.12141
Pawnee, C.I.11669

bulks are mostly wheat-like selections. Many of the lines in the plant- and headed-selected rust resistant material show the glumes adhering to the grain.

Kernel Colors. A variety of kernel colors was observed in the hybrid material. Red was the predominant color, but many of the intermediate types produced green and brown kernels. Various shades of green, from a bluish-green to a greenish-brown, were observed. White wheats apparently have been used in the crosses or backcrosses for some lines produced white kernels almost entirely.

A total of 1,683 heads were selected in the 1948 nursery for fall planting in 1949. While examining the grain of these heads, it was observed that the kernels were not all of the same color even in the same head. A closer check revealed that this occurred in 113 out of the 1,683 heads selected, or in 6.6 per cent of the heads. The 113 heads came from 64 different rows.

Wheat, normally, carries color only in the testa or the cross layers of the pericarp; this is maternal tissue and should therefore carry the same color in all of the kernels produced on one plant. Therefore, it appears that probably an aleurone color has been introduced into the hybrid material from the *Agropyron* parents or from the rye used in some of the crosses. The differently-colored kernels could, then, be due to segregation for factors governing the expression of aleurone colors and a manifestation of xenia. Masing (36), in reviewing the literature on xenia in wheat, concludes that it is not found in wheat unless interspecific or intergeneric hybridization has been employed. Aase (2) states that xenia is not readily discernable in the small grains. The introduction of an aleurone color into wheat is of considerable interest.

The different colors could have resulted from either self- or cross-pollination, depending on the homozygosity or heterozygosity of the factors governing the expression of color. It could, however, be assumed to indicate that a good deal of natural crossing is occurring between the hybrid lines in the nursery. Suneson and Pope (72) state that natural crossing in the more stable lines exceeds five per cent and is of much practical value.

Growth Anomalies. Dwarf seedlings were often observed in the lines tested for seedling reactions to leaf rust. One line also produced albino seedlings. A red banding was observed in three related rows adjacent to each other in the 1949 nursery. The bands, located half way up the youngest leaf, were observed when the seedlings were in the two to three leaf stage and about five inches tall. The fact that the bands were nearly equidistant from the ground level strongly suggests the possibility of an environmental influence.

Coleoptile Color. A green coleoptile color is characteristic of many wheat varieties, although some have coleoptiles showing varying degrees of red color. Many of the other grasses have distinctly red-colored coleoptiles, the color often being so dark as to approach purple. An attempt was made to correlate this red coleoptile color with leaf rust resistance; results indicated, however, that there was no apparent correlation between the two factors.

Salt Tolerance. In the salt test described under Materials and Methods, variation in tolerance was observed in the group of hybrids subjected to the sodium chloride (NaCl) treatment. The sodium sulfate (Na_2SO_4, anhydrous) treatment had no apparent harmful effect on any of the lines tested; in fact, the foliage appeared to be a more healthy bluish-green color when compared with the untreated checks. The group treated with the six grams of NaCl (which was added in two applications of one and five grams each), however, showed sharp differences. The two wheat varieties included, Westar and Nabob, also behaved differently. Nabob wilted badly in four days after the five grams were added and died soon afterward. Westar, on the other hand, was more tolerant than many of the wheat X Agropyron hybrids. When the final results were observed on the 12th day after the five grams of salt were added, Nabob, Westar, and 22 of the hybrid lines were dead, nine hybrids still had a few green leaves, three had quite a number of green leaves, and four were still in fairly good condition. Plate I shows the sharp differences obtained.

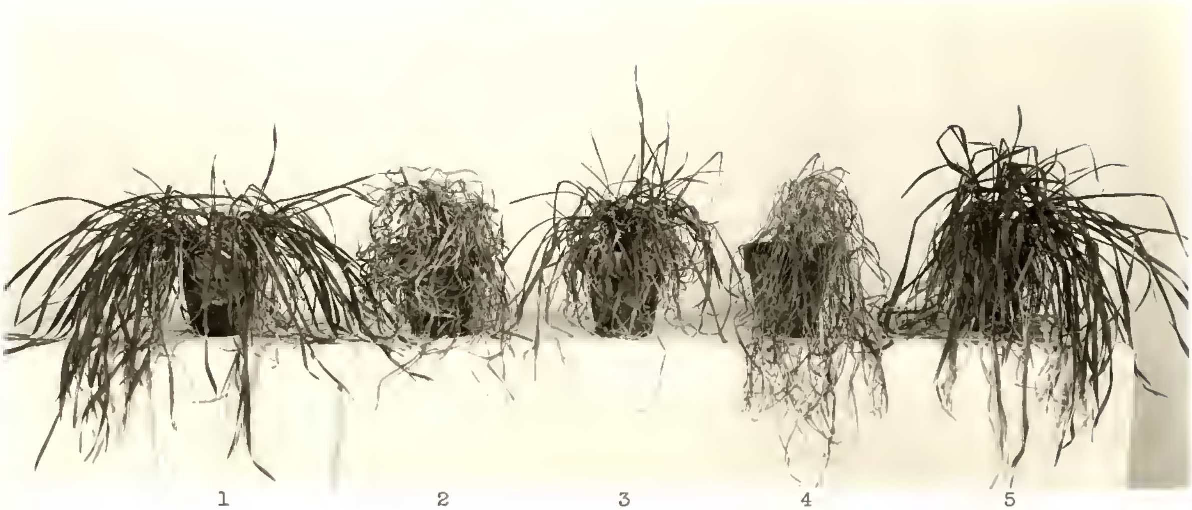
Failure of the sodium sulfate treatment to show effects similar to those obtained from the sodium chloride treatment might be due to the differences in actual sodium content of the two salts or to differences in toxicity of the chlorine ion as compared with that of the sulfate ion. Whether the effect was one of toxicity or plasmolysis was not determined. It was noted, however, that within 48 hours after the five grams of NaCl were applied, water uptake was reduced sharply.

An evaluation of the results is difficult since the salt tolerance of Wostar and Nabob in comparison with other wheats is not known. It is evident, however, that differences in sodium chloride tolerance, which may have been inherited from the Agropyron parent, existed in the hybrid material. This could possibly be utilized in developing wheats that would grow more readily on some of the saline soils.

EXPLANATION OF PLATE I

Result of the salt tolerance test showing killing variation. Left to right: 1. Untreated wheat, Westar, C.I.12110. 2. Westar killed by the sodium chloride treatment. 3. The hybrid most tolerant to the sodium chloride treatment. 4. A hybrid killed by the sodium chloride treatment. 5. Westar, unaffected by the sodium sulfate treatment.

PLATE I



CONCLUSIONS AND SUMMARY

The results of the rust tests substantiate the many reports of rust resistance in *Triticum*-*Agropyron* hybrids. It is evident that lines resistant to the most prevalent races of leaf and stem rust of wheat can be selected from the material now in the nursery.

The *Agropyron* species tested were immune to speckled leaf blotch of wheat, *Septoria tritici*, Rob. It is apparent that in hybridization with wheat, the *Agropyron* species transmit this high resistance to some of the hybrid progeny. Thus, a new source of resistance to *Septoria tritici* has been located. This is believed to be the first report of resistance of the *Triticum*-*Agropyron* hybrids to this disease.

A relatively high rate of ergot infection was observed in much of the material, regardless of *Agropyron* parentage. This agrees with the results reported by most of the Canadian workers. Less ergot infection was found in the more fertile and wheat-like lines. It appears that it would cease to be troublesome in highly fertile material.

The high degree of winterhardiness of the wheat X *Agropyron* hybrids reported by the Russian workers is not evident in the material studied. Some of the susceptibility to winterkilling may be due to spring wheat parentage. Backcrosses to winter wheat in the Mindum X *Agropyron tri-*

chophorum hybrids raised the survival percentages. This is contrary to the reported loss of winter survival when the hybrids were backcrossed to wheat.

In general, the hybrid material did not appear to be as vigorous as the wheat checks used.

In the material studied, selection has been made for the more wheat-like and disease resistant lines. Perennial habit of growth has not been selected for, and observations on plants showing regrowth indicate that perennial tendencies are rapidly being lost.

Most of the hybrids headed later than Pawnee, a standard wheat variety. A few lines were, however, equal to Pawnee in this respect. Hybrids earlier than the standard wheats appear to be the exception since the great bulk of the material studied was later; this suggests that the reports of hybrids heading much earlier than standard wheat varieties, have singled out these exceptional cases.

An analysis of the yield and test weight data shows that a few of the hybrids are nearly equal to some of the wheat checks in these characters. The bulk of the material is, however, far inferior to the wheat checks. This is to be expected since these factors are quantitatively inherited, and the crosses are extremely wide. The desired recombination may, perhaps, be obtained only after numerous backcrosses to wheats.

Real progress has been made in securing relatively easy-threshing and free-threshing lines. These wheat characters appear to be recovered without much difficulty.

While an evaluation of the salt resistance of the hybrids was not possible in the experiment reported, the data do indicate that a high variability for this character exists. This indicates the possibilities of securing hybrids highly tolerant to saline soils, as suggested by Skosyreva (66).

The many kernel colors reported for the hybrids have not been identified as aleurone colors. Data presented are, however, indicative of the presence of aleurone colors in the material studied. The introduction of an aleurone color into wheat is of considerable interest.

This survey of the hybrid material studied indicates that the large share of this material is probably worthless. However, the presence of exceptional lines indicates that the handling of large numbers followed by careful selection and backcrossing to wheat may bring the reward of obtaining a hybrid that is a "good wheat" in every respect and still retains some of the desirable Agropyron characters.

A review of the literature reveals that great potentialities exist in the intergeneric hybridization of the more closely related Triticum and Agropyron species. While the results obtained so far are not spectacular, it is remarkable that so much has been achieved in so short a time. This must be kept in mind when ascertaining the real measure of success attained.

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